WESTINGHOUSE

Engineer

NOVEMBER 1958

R AND D = DOLLARS AND CENTS

Research and development efforts can be measured in many ways: in terms of spectacular "breakthroughs"; by number of achievements in a given year; by laboratories and facilities; by caliber of engineers and scientists; by the nature of their investigations; by their overall contributions to science. All of these give some indication, but none are sufficient by themselves.

While all of these abstract yardsticks are important, in the long run research must also show an economic benefit, both to the company that supports it and to the customers who use its products. The results may not be apparent for years, and the end result may be a composite of many different research and engineering investigations—but in the end industrial research must pay for itself.

Within an industrial company, the value of its own research is reasonably evident, and stacks of figures can be compiled to show its worth. To the users of that company's products, however, the results are easy to overlook. Progress is expected, and how that progress came about, or its net effect, is not always apparent.

Part of the reason for this is that viewed individually most of the results of research and development are not spectacular. However, the cumulative effect over a period of years gives a clear indication of their value.

Take, for example, the pole-type distribution transformer, thousands of which are installed daily. In 1933 the price of a distribution transformer was made up of the cost of the oil, the copper, the iron, the labor, and the insulating materials that went into it. In the 25 years since then, the cost of electrolytic copper has increased 419 percent; the cost of electrical steel has increased 395 percent; and the cost of labor has increased 305 percent.

All told, the materials and labor needed to produce a distribution transformer have risen an average of 373 percent. In this same period, the price of distribution transformers has risen only 64 percent.

Considering a specific case, a 25-kva conventional single-phase transformer, with a high voltage of 7200, cost approximately $214 in 1933; the same transformer now costs about $350. But the differences don't stop there.

The 1933 transformer had an iron loss of 144 watts; today it has a guarantee of only 130 (or a 10 percent reduction). The same 1933 transformer had a total watts loss of 544; today it has 505 (or a 7 percent reduction). At an annual average load of 25 kva, this improvement in losses alone will save over $7 per transformer in annual operating costs.

But there's more. The 1933 transformer had a regulation of 3.5 percent; today, it has a regulation of 2.2 percent (both at 80 percent power factor). To translate this improvement into dollars, we should first establish that the voltage drop through a transformer is proportionate to its impedance. Lower impedance means less voltage drop, fewer voltage complaints, and more revenue.

If the cost of lost kwhr sales is figured at one cent per kwhr, a comparison of revenue loss due to regulation at 100 percent average annual load between today's transformer and the 1933 design reveals a savings of about $15 a year.

And because of its lower impedance, the 1958 transformer will carry 60 percent more load, yet not exceed the voltage drop of the 1933 design. While this is not an economic factor, it does make it possible for operators to work transformers at higher peak loads, which will reduce the number of transformer changeouts.

Added to the savings resulting from an improvement in losses, the total operating cost savings at 100 percent annual average load amounts to approximately $22. Now, $22 capitalized at 15 percent is about $147. But the cost increase from 1933 to 1958 is only $136, so the capitalized savings per year on the 1958 transformer, at 100 percent average load, are enough to wipe out the cost increase from 1933 to date. Continuing the comparison: The 1933 transformer weighed 615 pounds; today it weighs 470 pounds. This means savings in operational expense through ease of handling.

The 1958 transformer can carry higher peaks, and heavier loads when needed. For example, to carry a 54-kva peak for 2 hours in 1933, a 37½ kva transformer was used. Today this load can be carried by a 25-kva transformer.

These improvements speak only of net results. They don't mention the improvements that brought them about—the completely self-protecting design, Hipersil (a grain-oriented steel of superior magnetic properties), the Insuldur insulation system, and many others. However, one thing is crystal clear: Had not continuing research and development been aimed at improving the distribution transformer, we would still be using the 1933 design. Impose that same "no progress" situation on other equipment used in the electric utility business and the effect would be sizable, both in dollar revenue and in operation and maintenance.

Research and development are too often thought of only in terms of the improvements that are brought about; the fact that the achievements also mean dollars and cents is too often overlooked. Industrial research cannot survive unless it pays for itself.

COVER DESIGN: A different approach to an old subject was taken on this month's cover by R. G. Marsh Studios. Rather than a realistic view, the artist chose to create an impression of a coal mining machine burrowing its way through a seam.

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De-ion, Hipersil, Insuldur

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THE TREND TO LARGER TURBINE GENERATORS

. . . and the important factors concerned

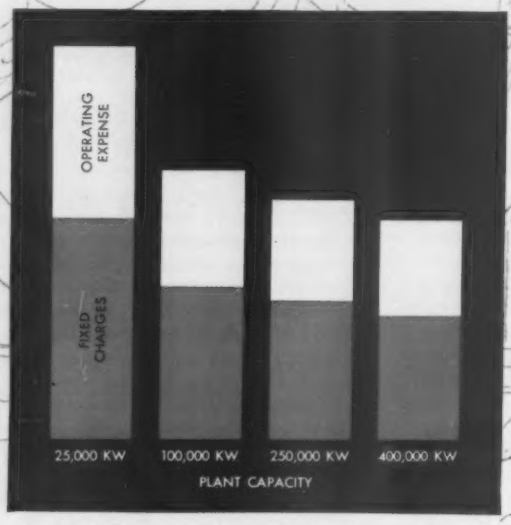

Fig. 1—Relative annual costs of thermal power for units of different size.

Maximum turbine generator sizes have been increasing by leaps and bounds. The various problems and factors involved in large units are discussed here.

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The relationships that affect the trend to larger turbine generator sizes can be summed up in one simple statement: Careful *system planning* of *generation expansion* is necessary if present and future power system loads are to be carried with adequate *reliability* at *minimum cost*. The question is—how can the system planner reduce power cost by economies in generation expansion?

The cost of power involves both fixed charges and production expense. With certain restrictions, both are decreased by increasing unit size. For any given plant, fixed charges decrease as capacity increases, and production expense decreases as unit efficiency increases along with unit size. This is illustrated in Fig. 1.

Additional savings are possible with unit sizes above 400 mw. Even a 1600-mw plant shows a prospective reduction of 4 percent in both construction and operating costs when compared with four 400-mw plants.

If costs and revenue requirements can be reduced by increasing unit size, then what limitations prevent the system planner from applying this principle to its extreme? There are two—(1) technological limitations and (2) reliability limitations—that come into effect as unit sizes get too large compared to system load. Usually reliability limits the application of large units on systems as they exist at present. The problem is this: as larger units are applied, more generation reserves must be maintained to provide for emergency or forced outages of units. In other words, a decreasing percentage of the capacity of the larger unit is available as firm power since an increasing percentage must be designated as reserve. Finally, the cost of the extra unused capacity counterbalances the savings made by installing large units. The exact balance point appears to determine the most economical expansion.

While this economic balance appears to limit application of larger units, it is valid only within the confines of a single

and isolated system. It can be negated by system interconnection, and herein lies the solution to the problem of applying larger units within given standards of reliability.

philosophy of system interconnection

Technology and system reliability are the two factors that limit the application of large generating units. To small systems, reliability is the more important limitation. However, interconnection with neighboring power systems provides a way to share generation reserves and thereby obtain substantial savings in both first cost and production cost. Thus, the concept of the power pool is introduced—the joint operation of independent utilities so that the effective reserves of each are increased and economy energy can be interchanged.

To accomplish system interconnections of high capacity, utilities have gone to extra-high-voltage transmission. Even with this additional cost, the economic advantages of interconnections are becoming more favorable. To illustrate, assume a hypothetical system with a 1000-mw load at the present and a forecasted load in five years of 1600 mw. If there were no interconnections, the units planned for installation in the next five years might be two 100-mw, two 125-mw and one 150-mw machines, for a total of 600 mw. These sizes would be determined by standard practices concerning generation margins and spinning reserves established in the past by certain rules-of-thumb. For instance, over the entire load period the system would have to carry spinning reserves equal to the largest unit in service. In addition, most noninterconnected systems require a minimum installed capability of at least 115 percent of system peak load, occasioned by a second contingency allowance. Even with this 15 percent margin, the loss of an entire station during a peak period would mean load shedding or system shutdown. Important economic gains could be obtained for this system from high-capacity interconnections. A tie line with a capacity of 200 to 250 mw would permit individual units of at least 200 mw to be used in the hypothetical system. Also, the total installed capacity could be reduced since the second contingency would be handled by adjacent system reserves.

System interconnection also provides advantages and economies in the matter of spinning reserve determination. Suppose the illustrative 1000-mw system is interconnected with other systems and that the annual peak load of the power pool is 6000 mw with a minimum daily peak of 3000 mw. This ratio of maximum daily peak to minimum daily peak is a conservative assumption for power pools. Again, speaking in generalities and applying common rules-of-thumb, assume that contract agreements require each system to maintain spinning reserve of 10 percent of present system load. With the minimum daily pool peak of 3000 mw, a minimum of 300 mw of on-peak spinning reserve is available to the assumed 1000-mw system, since the entire reserve of the pool is available to any system for emergencies.

To emphasize the advantage, assume that the last three machines purchased for this system were a 150-mw, a 200-mw, and a 250-mw machine for the total of 600 mw. On a day when the system peak load does not exceed 545 mw, only these three machines need be run, since 600 mw will serve 545-mw load with 10 percent spinning reserve. One present practice for systems without interconnections is to maintain spinning reserve equal to the capability of the largest unit running. In this case, without the interconnections a spinning reserve of at least 250 mw more than the system load would be required. For most systems old and inefficient machines would have to be run at partial load to have this reserve.

Thus interconnections provide the economies inherent in larger units. They also permit more of the older plants to be on cold standby, thereby saving the expense of running old units for spinning reserve. In addition, the required spinning reserve on a single system is determined under all load conditions by the interconnected system load and generation and not by the largest unit running on the single system. The latter benefit is becoming more apparent as an important economic factor in system interconnections.

The formation of power pools to reap these benefits accelerates the trend to extra-high-voltage transmission. This is so because interconnection ties must be large enough to move the blocks of power necessary to maintain the reserve. The problem is not one of straightaway transmission since power is moved by a process of displacement from system to system. Therefore, stability is not often of concern. Nevertheless, interconnecting lines must be designed to allow the full use of the reserve capacity of the entire interconnected system.

Power pools not only permit sharing of generation reserves, but also encourage the interchange of economy energy. The original concept considered such interchange only during off-peak periods. But now the time-zone effect, which gives noncoincident system and pool peaks, is being given more consideration. Also, systems are finding that an ever greater portion of their load is temperature sensitive. Yearly peak loads are occurring in the summer in a large area of the United States. In these areas system loads may be reduced as much as 40 percent on a cool day in the summer. When such an event is a local phenomenon, other systems in the power pool are likely to be operating near peak load with high incremental generating costs. This condition results in a situation where interchange of economy energy is dictated by the lower incremental generating costs of the lightly loaded system.

These simple examples show how the formation of power pools permits not only economy interchange and reapportionment of spinning reserves, but also a very significant reduction of reserve generating capacity. These examples make use of generalities and certain rules-of-thumb in common usage. Using similar methods, it is possible to show how power system interconnections might reduce margin requirements for individual load areas. But more recently the mathematics of probability has permitted a rigorous and consistent evaluation of just what risk of generation shortage is attendant with larger unit sizes.

theoretical treatment of generation expansion

With power systems becoming more complex, rule-of-thumb methods for determining generation reserves are less satisfactory as tools of system design. If too much reserve is provided, plant or capital will be idle. On the other hand, if the generation reserve is too small, the equivalent financial loss through alienation of customers' faith and goodwill may well exceed the actual loss of power sales. Present-day probability theory provides a more scientific basis for designing a system of large units for a given degree of reliability.

Probability methods make it possible to determine the probability of a forced outage of any given magnitude occurring during the period considered, usually over a month or a year. Only the number of units of each size, together with their outage rates, need be known. An outage rate is defined as the average duration of a unit forced outage divided by the interval between occurrences of forced outages of that unit. If a number of boilers and turbines are interconnected through a common steam header, then arrangement, capacities, and outage rates of the boilers must be known too.

With size and outage rates known, conventional probability principles are applied to obtain a table of probabilities of generation capacity outages of various magnitudes. These are combined with the forecast daily peak loads as adjusted for scheduled maintenance, seasonal output limitations, and emergency overloading of units. The result is the probability of a *loss of load* occurring during the period considered. This loss of load probability is, strictly speaking, the ratio of the probable duration of loss of load to the duration of the period considered. It is usually expressed as the inverse, or "years per day of loss of load" or "one day per X years." One day in 8 or 10 years is often considered an acceptable risk of shortage, although the figure varies, depending on the worth assigned to reliability.

For a given generating system and forecast load values, the effect of interconnections on the loss of load probability can be determined by assuming that the capacity of the interconnection is equivalent to additional generating capacity having negligible outage rate. The probability of a forced outage occurring on a tie line could be included, but the outage rate of tie lines is usually low compared to that of a generator. Then revised values of loss of load probability will show the effect of additional interconnections in reducing the risk of shortages. Or, if risk of shortage is plotted against interconnection capacity for various expansion plans, the proper interconnection to maintain a given risk of shortage can be determined.

An Existing Model System. To this point the risk of shortage concept has been applied only to a system with interconnections to other power pool members. The same principles can be applied to a nonintegrated system with sufficient generation concentrated in each loosely connected load area. Ties between load areas are then "intraconnections," and these reduce area reserve requirements just as interconnections reduce integrated-system reserve requirements.

To illustrate this principle, a model system was developed with a total present generating capacity of 2310 mw located in six major load areas designated as Alpha, Beta, Gamma, Del-

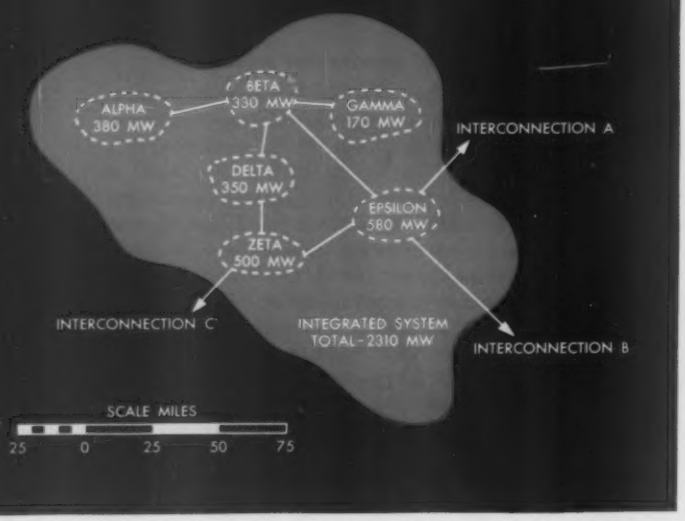


Fig. 2—The existing model system, showing area capacities and major tie lines.

TABLE I
MODEL INTEGRATED SYSTEM (PRESENT)

Unit Size mw	Outage Rate %	Region						Integrated System
		Alpha	Beta	Gamma	Delta	Epsilon	Zeta	
10	2	1	1	3	1	—	—	6
20	2	2	2	2	3	2	4	15
30	2	4	3	2	3	4	2	18
40	2	1	2	1	2	2	1	9
50	2	1	1	—	1	—	1	4
60	3	2	1	—	1	2	2	8
70	3	—	—	—	—	2	1	3
80	3	—	—	—	—	1	1	2
Total Generation Capacity, mw		380	330	170	350	580	500	2310
Maximum Daily Peak (Adjusted)		340	290	150	320	540	460	2100
Minimum Daily Peak (Adjusted)		280	230	120	260	440	370	1700

TABLE II
PRESENT INTRACONNECTION AND INTERCONNECTION CAPACITIES IN MW TO GIVE INDICATED PROBABILITIES OF LOSS OF LOAD

Probability of Loss of Load	Region						Integrated System
	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	
1 day in 3.7 yrs.	57	51	35	62	104	94	0
1 day in 8.0 yrs.	69	62	41	72	125	110	40
1 day in 23.7 yrs.	84	75	49	86	160	136	150

TABLE III
MODEL INTEGRATED SYSTEM (FUTURE)

	Region						Integrated System Total
	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	
Present Generating Capacity, mw (see Table I)	380	330	170	350	580	500	2310
FUTURE EXPANSION PATTERN:							
Plan (a) 120-mw units	2				2	2	6
Plan (b) 240-mw units	1				1	1	3
Future Generating Capacity	620	330	170	350	820	740	3030
Future Max. Daily Peak (Adjusted)	450	380	190	420	700	610	2750
Future Min. Daily Peak (Adjusted)	360	300	150	330	570	490	2200

TABLE IV
FUTURE INTRACONNECTION AND INTERCONNECTION CAPACITIES IN MW TO GIVE A PROBABILITY OF LOSS OF LOAD EQUAL TO 1 DAY IN 8 YEARS

	Region						Integrated Sys. Total (Future)
	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	
FUTURE EXPANSION PATTERN:							
Plan (a) 120-mw units	43	150	77	165	115	100	100
Plan (b) 240-mw units	118	150	77	165	185	190	250

TABLE V
AVERAGE NUMBER OF TIMES PER YEAR THAT INTRACONNECTIONS AND INTERCONNECTIONS OF UP TO AND INCLUDING CAPACITIES OF TABLE IV WILL BE REQUIRED TO GIVE A PROBABILITY OF LOSS OF LOAD EQUAL TO 1 DAY IN 8 YEARS

	Region						Integrated System (Future)
	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	
FUTURE EXPANSION PATTERN:							
Plan (a) 120-mw units	.31	Constantly	200	Constantly	3.57	1.88	.35
Plan (b) 240-mw units	6.67	Constantly	200	Constantly	7.70	7.00	1.56

ta, Epsilon, and Zeta. The capacity assumed in each area and the intraconnections between each are shown in Fig. 2, together with interconnections A, B, and C to other power pool members. Probability calculations were applied to this model system to show the improved area reliability secured by tying load areas together and the improved integrated-system reliability secured by adding interconnections to neighboring utility systems.

To simplify calculations, the composition of the capacity in each area was assumed to be that listed in Table I. Also assumed was the distribution of the adjusted daily peak loads: linear variation from a value about 10 percent below area generating capacity to a minimum of 80 percent of the maximum daily peak. Weekday peaks alone were considered, making a month composed of 21 days and a year of 252 days. A 2 percent outage rate was used for units of 50 mw and below, while 3 percent was assumed for those above, on the basis that they would be at higher pressure and would likely be of the unit type with higher outage rates than the smaller common-header units. Finally, peak loads in the six areas were assumed to coincide and the maximum and minimum daily peaks for the Integrated System were established as the sums of the respective peaks in the individual areas. Error in this final assumption increases the value of connecting tie lines beyond that to be shown.

From the figures of Table I and the above assumptions, the value of intraconnections between the six areas taken as individual systems was determined; an example for the Alpha system is shown in Fig. 3. The curves illustrate how additional intraconnection capacity reduces the probability of loss of load. Similar calculations treating the integrated system result in Fig. 4. This shows the reduction in the probability of loss of load as interconnection capacities are increased with pool members A, B, and C.

Consider first the risk of shortage to the Integrated System without interconnections; it is 1 day in 3.7 years, a considerably better value than that of any isolated area by itself. The first line of Table II gives the area intraconnection. The third line of Table II shows the area intraconnections necessary to bring the loss of load probability of each to that of the Integrated System with interconnections of 150 mw. The second line of Table II shows the intraconnection to each area that results in the often-accepted risk of shortage of 1 day in eight years.

A Future Model System. In the above example probability methods have been used to determine the value of intraconnections between the various areas of an existing system. The methods, however, are equally valuable in comparing different generation expansion patterns to meet anticipated future load development. Suppose that a future peak of 2750 mw is anticipated two years hence, and that a comparison is desired between: Plan (a), adding six 120-mw units and Plan (b), adding three 240-mw units to the existing Integrated System. In either case, the capacity is increased by 720 mw, and the reserve will be the same percentage of peak.

For illustrative purposes, Plan (a) is assumed to add two 120-mw units in the Alpha area, two the Epsilon area, and two in the Zeta area. Plan (b) adds one 240-mw unit in each of these three areas. The future generation capacities and loads in each of the six areas are listed in Table III. Since area loads have been assumed to increase uniformly, area reserve capacities will no longer be equal percentages. Instead they will be considerably higher in areas to which new units are added, while in the other three areas, future load will exceed the generating capacity. These areas will be entirely dependent on intraconnections to neighboring areas, as might be expected from the use of large unit sizes to meet the assumed uniform load growth.

The results of the two expansion plans for the single integrated system are shown in Fig. 4. Curves (a) and (b) show that for a given generation reserve capacity of 10 percent and any given probability of loss of load, higher interconnection capacities are required with the 240-mw units than with the 120-mw units. Since smaller units now make up the system, existing interconnection requirements are less than either of the future alternatives. From a different point of view, if the

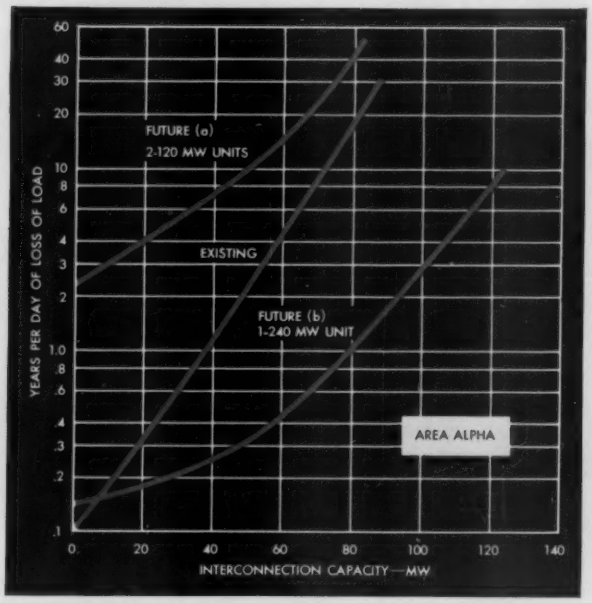


Fig. 3—Additional intraconnection capacity reduces the probability of loss of load.

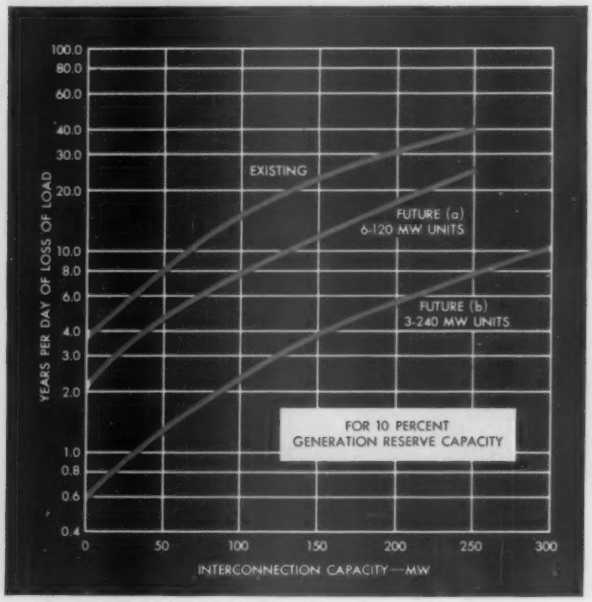


Fig. 4—The risk of shortage curve for the entire model integrated system.

magnitude of the interconnection is limited, the larger units would require generator reserve capacities greater than 10 percent to give the same probability of loss of load. This viewpoint is illustrated in Fig. 5 by a plot of the percentage reserves required versus interconnection capacity for a risk of shortage of 1 day in 8 years.

The intraconnection and interconnection capacities required for a risk of shortage of 1 day in 8 years for either of the alternate plans is shown in Table IV. The average number of times per year that tie lines up to these capacities will be required is shown in Table V. The areas where no units were added will be dependent on their ties to the rest of the system.

In summary, larger unit sizes require increased tie line capacities to give the same loss of load probability obtainable from smaller sizes. The cost of these tie lines is small compared to the cost of reserve generation to provide the same reliability. Therefore, so long as each area or system maintains its share of total generation, considerable improvement in reliability can be obtained by intraconnection and interconnection while the economic benefits of large units are enjoyed by the power pool.

present worth evaluations

As a power system's load grows, probability calculations will indicate when an addition to generating capacity is necessary to keep the risk of shortage from exceeding any desired value. However, these calculations do not indicate the size of unit to add, its head rate, its location, or even the type of fuel to use. True enough, probability calculations will show the effect of adding a large unit in delaying the addition of the subsequent unit. But only an economic evaluation will show which plan results in the lowest revenue requirements.

A commonly accepted fact is that the expenditure of money at some future date is equivalent to the expenditure of a lesser sum at the present. The future sum of money is said to have a "present worth," and compound interest tables are available to determine the present worth of any future sum. Furthermore, another obvious fact is that a generating expansion plan executed now influences the decision as to the next expansion plan and all other future plans. An example of this is the delay in unit additions caused by the selection of a unit size larger than necessary for the immediate load. If future plans are changed, their present worths are changed, and the logical conclusion is that future expansion patterns in part determine the immediate plan to be selected as the most economical.

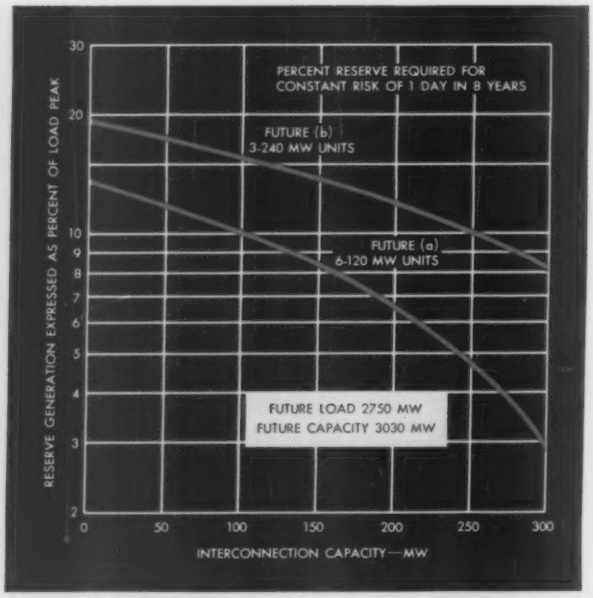


Fig. 5—Percentage reserves required versus interconnection capacity.

Suppose the immediate decision rested between three possible unit sizes, locatable at any of four plant sites, with two possible heat rates available for any size. The possible alternates are twenty-four. Furthermore, when the load again reached the point that a second expansion became necessary, the same twenty-four alternates might be possible. So the alternates "branch," and the proper choice now is the one with minimum present worth for one of its many alternate branches. This plan branch, if followed, would result in minimum revenue requirements over the period of the study.

The problems arising from such an investigation are many and complex, far beyond the scope of this article. While the data processing itself is enormous, the basic problem is the formalizing of the logic involved in the management-type decisions. With modern high-speed computing machinery now available, there is some hope that a partial solution to the problem is possible. In any case, the real value of such a study will be the reduction of such decisions to a scientific and logical method based on consistent principles.

summary of significant factors

The selection of a generating unit size for a system expansion plan is not a simple matter. Many factors influence the selection, and their interrelations are not all clear-cut. The preceding paragraphs have extolled large unit sizes as having lower capital cost per megawatt and lower operating costs per kilowatthour. Capital cost savings arise from lower equipment costs per megawatt for larger sizes, lower construction costs per mw, more efficient use of sites, and lower cost per mw of expansion capital. Operating cost reductions come from better heat rates and lower labor and maintenance expenses on a per mw basis. In addition to these advantages, large units encourage system interconnections, which permit interchange of economy energy.

Several factors oppose the application of large units on the basis of pure economics. The most prominent of these is the increase of reserve capacity required to maintain a given risk of shortage. The larger the unit size, the greater is the percentage of its capacity that must be maintained as nonincome producing reserve. Transmission interconnections reduce the percentage reserve required. Because interconnections are cheaper than generation capacity, larger units can be applied than would be the case if size were determined by load growth alone. Therefore, a second factor opposing the trend to large units is increasing transmission costs. As transmission costs increase per megawatt capacity, justification of larger units becomes more difficult. A third factor slowing the trend to large units would be any increase in forced outage rate for the large high-pressure, high-temperature machines. A higher outage rate means proportionally more reserve must be allocated and hence higher capital costs per megawatt of available capacity. And finally, if the rate of load growth is abnormally low, large units may not be justifiable.

Each system must be analyzed on its own merit. In the final analysis, the size of the unit to be added will be determined by an economic study comparing alternate plans on a present-worth basis. ■

Industrial training programs aid college graduates in the transition from college to industry, and must keep pace with changes in education and engineering.

GRADUATE STUDENT COURSE

. . . transition from classroom to industry

The emphasis in college engineering curricula during the past few years has shifted strongly toward the fundamentals of science as opposed to the application of those fundamentals. What this adds up to is that the engineer with a new bachelor degree—while better equipped with an engineering-science background than ever before—lacks a knowledge of practices, techniques, and engineering application that will enable him to immediately adapt his college studies to industrial problems. While few would oppose this trend, the fact remains that the graduate must bridge a reasonably well-defined gap in his transition from college to industry.

To a degree this has always been true, and programs such as the Westinghouse Graduate Student Course have been designed to aid the transition. However, the shift in college curricula has meant that the industrial programs must be changed accordingly and, in some cases, pick up the "application" courses that are tending to disappear from college courses. Recently, the Graduate Student Course has undergone changes to keep it in tune with current trends.

The changing educational picture is not the only factor involved in the changes in the Student Course. Engineering itself is changing. The "team" effort of groups of scientists and engineers toward a common goal has become more and more common. This places heavier emphasis on such things as good communications and human relations, and this has been recognized in revising the course.

objectives of the student program

The Graduate Student Course has several primary objectives. First is *indoctrination* into a large and complex organization. Most students have limited industrial experience and thus face a period of general acclimation. Equally important is learning about their new employer, his products, his policies, and his practices.

Another important objective of the program is *identification of the abilities, interests, and strengths* of each student through job experience and effective testing, buttressed by counseling, and guidance. These assure that the student finds the right functional area (i.e., engineering, manufacturing, sales, etc.) and help establish training assignments.

Achieving the best possible match between the individual and the available job openings is a third and important objective.

Indoctrination—The first two weeks of the Graduate Student Course are called "Operations Westinghouse." Here the intent is to give the graduate a breadth of understanding and knowledge of the organization of the company—from the top echelon of management down to the inner workings of an operating division. Line and staff activities are defined and explained, and considerable emphasis is placed on objectives of the corporation. Because engineering graduates sometimes tend to lose sight of their responsibility for contributing to profits, some time is spent on the economic aspects of the corporation. Here also are outlined many of the responsibilities of the professional man in Westinghouse.

Guidance and Counseling—Once the orientation period is completed the student moves into the first major step in the process of training and placement. Statistically speaking, the functional needs for technical manpower in Westinghouse break down on a percentage basis roughly as follows: 55 percent for engineering, 22 percent for manufacturing, 20 percent for sales, and 3 percent for miscellaneous functions, such as purchasing, budget, etc. In extending offers to qualified graduates, these requirements are, of course, kept in mind. Either through the student's expression of preference, or the interviewer's recommendations, a student is tentatively identified with a function, such as engineering.

One function of the Student Course in this respect is to counsel and guide each individual into that function where his abilities, interests, and growth potential can be used to the maximum extent. During the Operations Westinghouse program, each student is assigned a counselor, whose job is to make a complete study of the graduate's college record, his aptitudes and abilities, his preferences, and assist the graduate in finding the right niche. Extensive supporting data is available to the counselor, among them being test measurements covering interest patterns, knowledge of field, and professional potential.

The function of the counselor, therefore, is to assist the student in making the right decision, consistent with the individual's abilities and interests, and the corporation's manpower needs. Where doubt exists in the mind of the student as to the function he prefers, assignments in the two different functions are arranged. Thus the student can experience in a general way the professional demands of each career.

specialized training

Having had a general orientation and decided upon his functional field, the graduate then begins to intensify his training in his chosen area. In general, regardless of the function involved, this consists of two things: experience assignments in an operating unit, interspersed with specialized training schools.

The graduate and his training supervisor jointly work out an average of four work assignments, each of four weeks duration. Two of these assignments are primarily for training purposes; the other two are to assist in final placement.

These assignments serve several purposes. First, they provide the student with realistic professional experience. Also, they give the student an opportunity to view an operation of the company, and therefore get a better insight into that activity. These same assignments also, of course, give the operating division a chance to observe the individual. All of this builds the foundation for eventual placement in the division—should the division, the student, and the training supervisor agree as to the correctness of such an action.

Notable exceptions to this assignment concept are the sales, accounting, and industrial relations training programs. In sales, for example, the young engineer is given assignments to enable him to pick up product know-how that can be applied to customer's problems in the field.

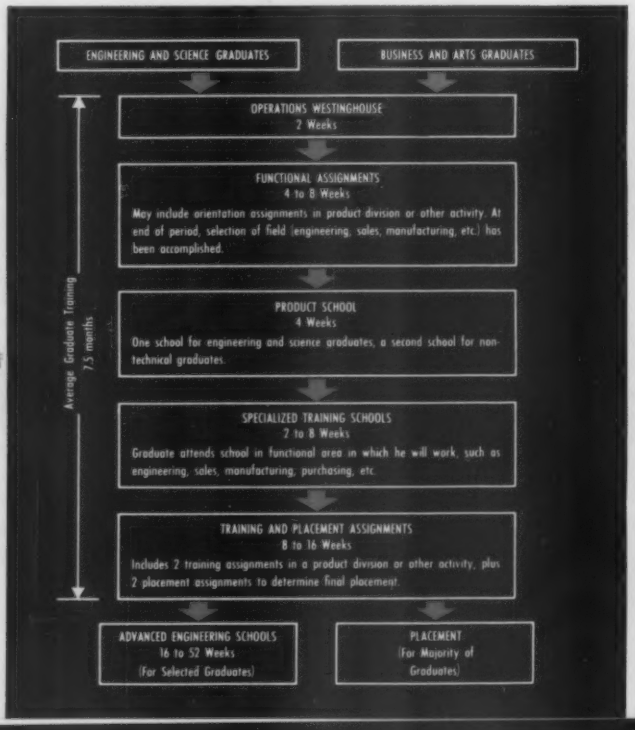
Specialized training courses are set up for those subjects that can be most effectively presented to a group on an instructor-student basis (see tables on page 169).

Technical Product School—This four-week school is designed to explain the products of the corporation to engineers and science graduates who plan to enter engineering, manufacturing, or sales. The main objective is to provide a broad picture of the company's products, including current and future developments, manufacturing processes and techniques, and the factors affecting the marketing of each product. These classes are conducted by representatives of the various activities, with emphasis on student participation.

Product School for Business and Arts Graduates—Regardless of what function the nontechnical graduate ultimately chooses, he will be involved with technical people and technical aspects of business, and should be familiar with them. Therefore, a separate product school for nontechnical graduates includes not only a familiarization with products, but also with technical terms and concepts.

Engineering School—The purpose of the engineering school is to help the graduate apply the knowledge gained in the college classroom to industrial problems and situations.

For example, one aim of the program is to acquaint the graduate with the work and responsibilities of an engineer in a division. Another is to show him what supporting functions are available to him and how they can assist him in his work. Still another aim is to suggest how he can develop or improve his creative thinking, as an aid to problem solving.


ENGINEERING AND SCIENCE GRADUATES
BUSINESS AND ARTS GRADUATES
OPERATIONS WESTINGHOUSE
2 Weeks
FUNCTIONAL ASSIGNMENTS
4 to 8 Weeks
May include orientation assignments in product division or other activity. At end of period, selection of field (engineering, sales, manufacturing, etc.) has been accomplished.
PRODUCT SCHOOL
4 Weeks
One school for engineering and science graduates, a second school for nontechnical graduates.
SPECIALIZED TRAINING SCHOOLS
2 to 8 Weeks
Graduate attends school in functional area in which he will work, such as engineering, sales, manufacturing, purchasing, etc.
TRAINING AND PLACEMENT ASSIGNMENTS
8 to 16 Weeks
Includes 2 training assignments in a product division or other activity, plus 2 placement assignments to determine final placement.
Average Graduate Training 7.5 months
ADVANCED ENGINEERING SCHOOLS
16 to 52 Weeks
(For Selected Graduates)
PLACEMENT
(For Majority of Graduates)

PRODUCT SCHOOL

4 Weeks

Objectives

1. Familiarize graduates with Westinghouse products.
2. Demonstrate relationships of engineering, sales manufacturing, etc., to products.
3. Provide student with knowledge of Westinghouse facilities and locations.
4. Provide student with understanding of objectives and responsibilities of product divisions.

Curriculum for Technical Graduates

1. Major product lines.
2. Basic engineering principles of major products.
3. Specific engineering, manufacturing, and sales features of major products.
4. Future products, plant facilities, field trips.

Curriculum for Nontechnical Graduates

1. Elementary electrical and mechanical engineering principles.
2. Major product lines.
3. Commercial aspects of product lines.
4. Plant facilities and field trips.

Other aspects of the engineering school are a review of report writing and oral presentation, to stress the importance of communications. The principles of human relations, which have a large bearing on any engineer's professional development, are also emphasized.

Manufacturing School—For graduates who go into manufacturing, an eight-week course provides a comprehensive understanding of the role of manufacturing in Westinghouse. Emphasis is placed on planning; control of production, inventory, and product quality; operations; and shop and laboratory experience. Following this course, manufacturing engineers are permanently placed in one of the operating divisions. Here they will normally undergo a one year on-the-job rotational program to provide them with experience in the planning, control, and operating activities of that division. At the end of a year, these manufacturing students attend a one-week seminar at headquarters before returning to their permanent position.

Sales Schools—To assure that students receive the necessary background for sales work, and yet do not have to attend sessions not related to their particular field of sales, the sales schools are three in number. First is a basic two-week course, covering general company sales policies and procedures that apply to all fields. All sales students attend this school. Sales schools two and three provide additional training in commercial analysis, pricing, sales strategy, and planning as applied to the product groups involved.

Other Schools—Other schools include a four-week course in purchasing, and two-week courses in accounting and budgets.

Advanced Schools—A carefully selected group of engineering students go on to more advanced training. These advanced programs are designed to accelerate the technical development of the selected engineers, and better equip them for the most complex technical tasks.

Students are chosen for this advanced training by a committee, which bases its decision on college and Graduate Student Course performance, as well as on the student's motivations and interests. Test scores are also a factor.

Three different programs are involved. The first of these is Design School, an intensive four-month program for graduates in engineering physics, and electrical or mechanical engineering. The course consists primarily of advanced mathematics, mechanics of materials, and systems engineering. A maximum of 60 students a year attend, and receive 15 credits toward an MS or PhD at the University of Pittsburgh.

For mechanical engineering students, a one-year advanced program is conducted at the Research Laboratories for a maximum of 12 students per year. This course, which covers stress analysis, heat transfer, fluid mechanics, dynamics and vibrations, mathematics, and thesis, earns the student an MS in ME at the University of Pittsburgh.

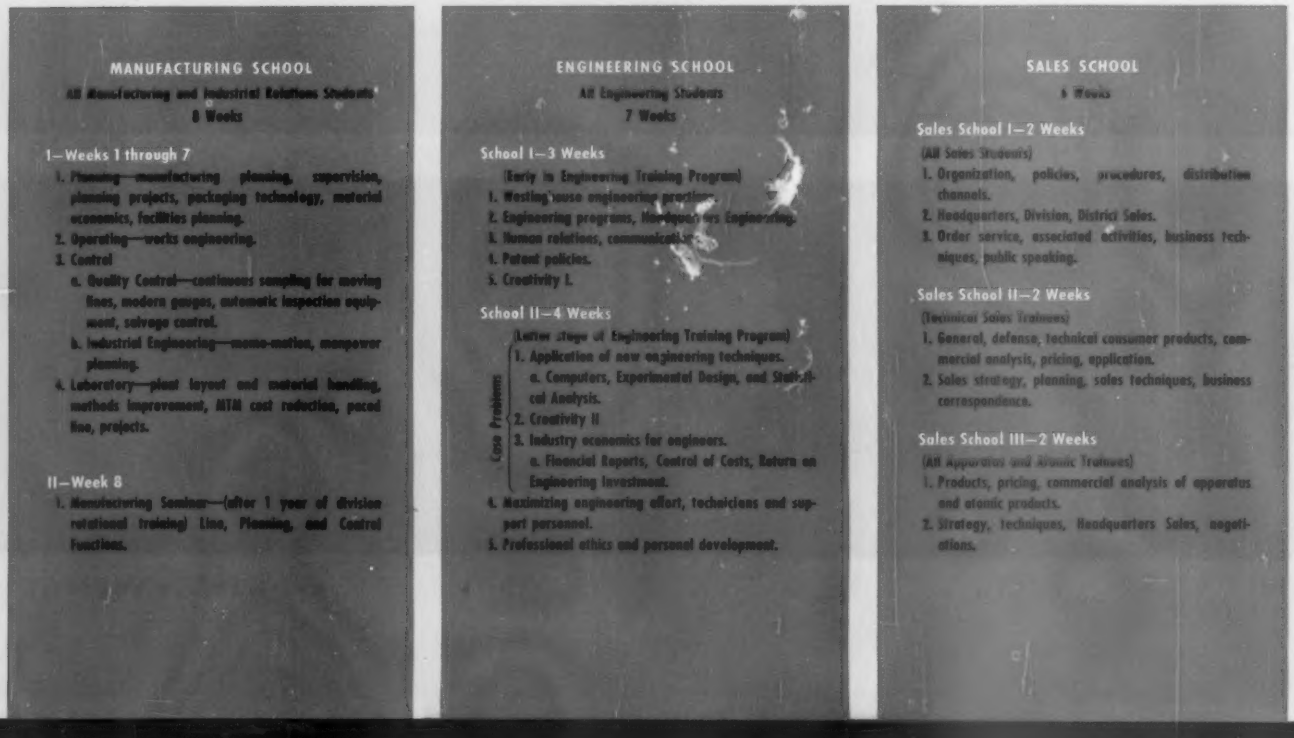
Both of the above programs are continuous and full-time courses. A third program involves both full and part-time participation over a four to five year period. Students attend Design School, then do advanced graduate work on a part-time basis. They are then granted a one-year leave for their PhD thesis. Students with degrees in electrical or mechanical engineering, or engineering physics, are chosen.

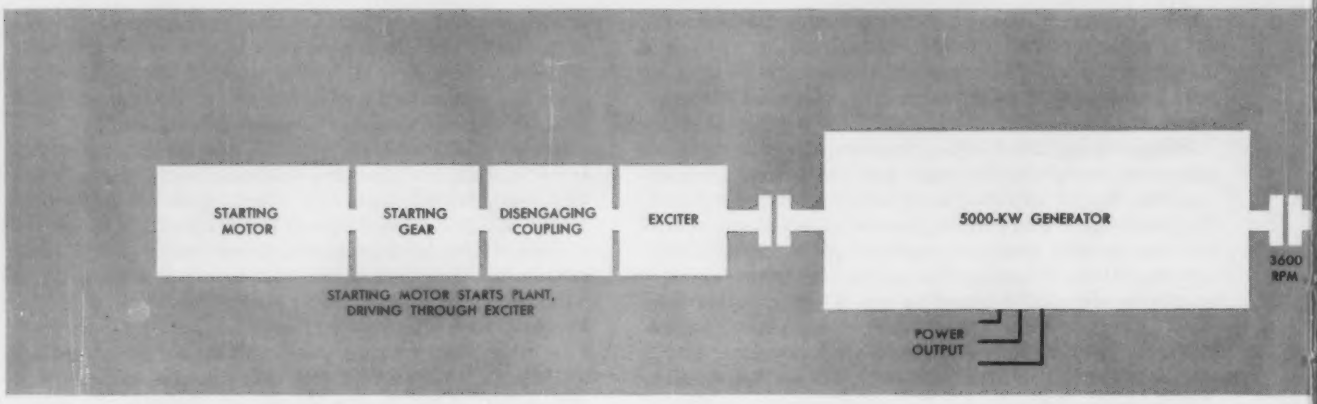
general considerations

While the name Graduate Student Course may suggest a standardized, stereotyped training program, nothing could be further from the truth. Actually, there are nine different functional training programs and the variations within these programs are almost unlimited. Thus the needs of the inexperienced college graduate, as well as those of his classmate with some experience, can be equally well filled.

By this system, the proper placement of the graduate is virtually assured, since ultimate placement is based on the training assignments. Before final placement is made, the student and operating activity are well acquainted with one another and have a firm basis for final decision.

Maintaining an effective program requires a sensitivity to changes in college educational emphasis, the students' needs, and the changing pattern of engineering in industry. For example, one current program now in progress is a "follow-up" survey, in which all men who have attended the Graduate Student Course are interviewed in depth each year for five years after placement. This is aimed largely at checking on the man's performance, progress, and potential for future technical or managerial advancement. Through such efforts, the Graduate Student Course effectively accomplishes the transition from classroom to industry, and gives the graduate a foundation on which to build a professional career. ■


MANUFACTURING SCHOOL
All Manufacturing and Industrial Relations Students
8 Weeks
I—Weeks 1 through 7
1. Planning—manufacturing planning, supervision, planning projects, packaging technology, material economics, facilities planning.
2. Operating—works engineering.
3. Control
a. Quality Control—continuous sampling for moving lines, modern gauges, automatic inspection equipment, salvage control.
b. Industrial Engineering—memo-motion, manpower planning.
4. Laboratory—plant layout and material handling, methods improvement, MTM cost reduction, paced line, projects.
II—Week 8
1. Manufacturing Seminar—(after 1 year of division rotational training) Line, Planning, and Control Functions.
ENGINEERING SCHOOL
All Engineering Students
7 Weeks
School I—3 Weeks
(Early in Engineering Training Program)
1. Westinghouse engineering practices.
2. Engineering programs, Headquarters Engineering.
3. Human relations, communications.
4. Patent policies.
5. Creativity I.
School II—4 Weeks
(Latter Stage of Engineering Training Program)
Case Problems
1. Application of new engineering techniques.
a. Computers, Experimental Design, and Statistical Analysis.
2. Creativity II
3. Industry economics for engineers.
a. Financial Reports, Control of Costs, Return on Engineering Investment.
4. Maximizing engineering effort, technicians and support personnel.
5. Professional ethics and personal development.
SALES SCHOOL
6 Weeks
Sales School I—2 Weeks
(All Sales Students)
1. Organization, policies, procedures, distribution channels.
2. Headquarters, Division, District Sales.
3. Order service, associated activities, business techniques, public speaking.
Sales School II—2 Weeks
(Technical Sales Trainees)
1. General, defense, technical consumer products, commercial analysis, pricing, application.
2. Sales strategy, planning, sales techniques, business correspondence.
Sales School III—2 Weeks
(All Apparatus and Atomic Trainees)
1. Products, pricing, commercial analysis of apparatus and atomic products.
2. Strategy, techniques, Headquarters Sales, negotiations.



GAS TURBINES FOR ELECTRIC UTILITY SYSTEMS

The industrial gas turbine has applications, both immediate and future, in the electric utility field. The potential advantages of combined steam and gas turbine cycles merit investigation.

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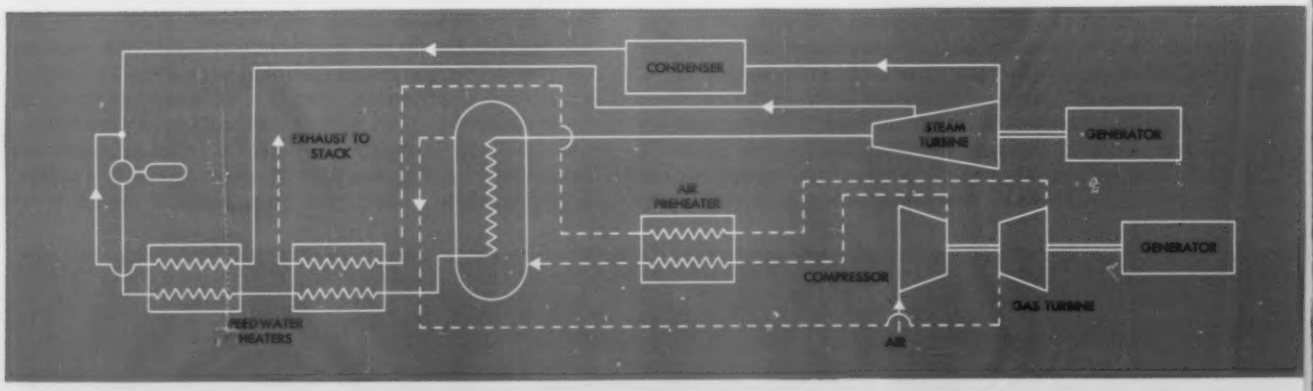
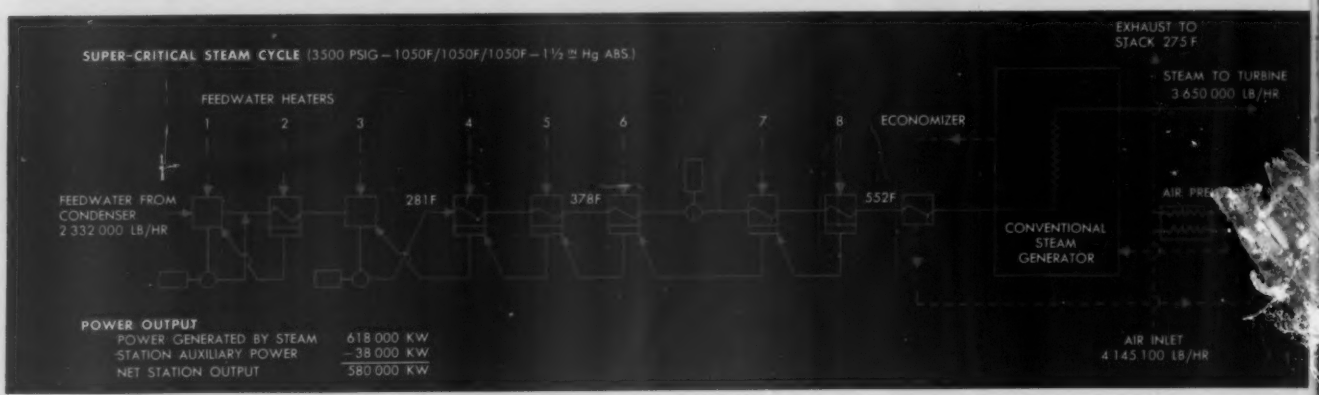
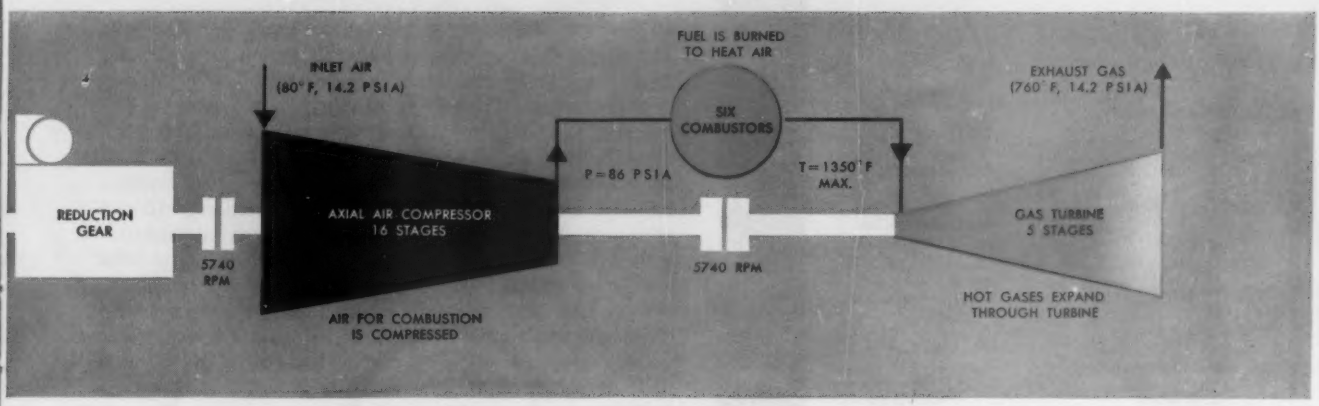



SUPER-CRITICAL STEAM CYCLE (3500 PSIG – 1050F/1050F/1050F – 1½ in Hg ABS.)
EXHAUST TO STACK 275 F
STEAM TO TURBINE 3 650 000 LB/HR
FEEDWATER HEATERS
1 2 3 4 5 6 7 8
ECONOMIZER
FEEDWATER FROM CONDENSER 2 332 000 LB/HR
281F
378F
552F
CONVENTIONAL STEAM GENERATOR
AIR PREHEATER
POWER OUTPUT
POWER GENERATED BY STEAM 618 000 KW
STATION AUXILIARY POWER −38 000 KW
NET STATION OUTPUT 580 000 KW
AIR INLET 4 145 100 LB/HR

require a boiler, boiler auxiliaries, or condenser. Its light



The gas turbine, a relative newcomer to the industrial prime-mover field, is making rapid strides in adapting itself to a variety of industrial environments. From the early 1950's, to the end of 1955, more than one million horsepower had been installed, or was being built. Today, more than four million horsepower has been installed or is being built by gas-turbine manufacturers worldwide. Gas turbines have demonstrated their reliability in natural-gas transmission, oil-field pressure maintenance, refinery and chemical plants, and electric power generation. In the electric utility industry, the gas turbine has only scratched the surface of its potential application. Many desirable and valuable features of the gas turbine have not been fully evaluated in an industry that has geared its economic analysis and criteria to the steam turbine.

There is an immediate application for gas-turbine power generation for peaking and standby service, and some special cases for base-load power generation. The gas turbine, in combination with the steam cycle, is potentially the next big step in the improvement of heat rates in base-load power generation plants.

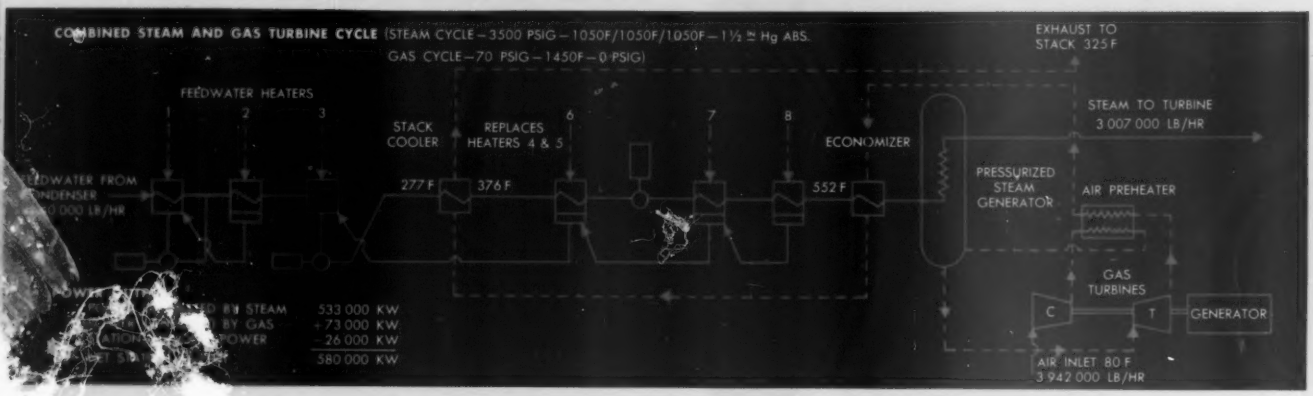
gas turbine characteristics

Many gas-turbine characteristics, both technical and economic, differ considerably from characteristics of the more familiar steam turbine. Installed cost is lower because the gas turbine is an internal-combustion machine that does not

Fig. 1—Simple schematic diagram (top) of industrial gas turbine.

Fig. 2—Simplified schematic diagram (left) of pressurized-boiler cycle.

Fig. 3—Comparison of steam-gas turbine combined cycle and straight supercritical steam cycle (bottom).



of a building comparable to indoor steam installations. The

BOX A—STEAM TURBINE VERSUS GAS TURBINE FOR PEAKING POWER

Steam Turbine Base Load Unit		
Fixed Charge	15% x $175	=$26.25
Attendance	Table II	= 2.91
Maintenance	Table III	= 3.00
Total Cost with Steam Turbine		=$32.16 per installed kw per year
Gas Turbine Peaking Unit		
Fixed Charge	15% x $135	=$20.25
Attendance	Table II	= 0.97
Maintenance	Table III	= 2.00
Estimated Additional Fuel Expense		= 5.13
Total Cost with Gas Turbine		=$28.35 per installed kw per year

BOX B—STEAM TURBINE VERSUS GAS TURBINE FOR END-OF-LINE PLANT

Transmission Line 40 Miles x $40 000 per Mile		=$1 600 000
Terminal Equipment		
Transformer and Breaker		= 100 000
		$1 700 000

Cost per kilowatt of the line
$1 700 000 / 16 500 kw = $103 per kw

Cost per kilowatt of power and losses
8760 x .50 x $.007 x 1.056 = $32.40

The factor 1.056 accounts for 5.6 percent loss in the transmission line.

Steam Power and Transmission Lines		
Fixed Cost	15% x $103	=$15.45
Cost of Power & Losses		= 32.40
Total Cost Using Steam Turbine		=$47.85 per installed kw per year
Gas Turbine Plant		
Fixed Costs	15% x $135	=$20.25
Attendance Costs	Table II	= 2.42
Maintenance	Table III	= 3.00
25 000 Btu x 15c x 8760 x .50 (Fuel: kwhr, 10^6 Btu)		= 16.42
Total Cost Using Gas Turbine		=$42.09 per installed kw per year

BOX C—DEFERRED INVESTMENT: STEAM PLANT VERSUS GAS TURBINE

Cost of Steam Plant and Accompanying Electrical System	
100 000 kw x ($135+$20 per kw) x 15% x 4 years	=$9 300 000
Cost of Gas Turbine Plant and Accompanying Electrical System	
Recovery of Investment 2 x 16 500 kw x ($135+$20)	= 5 115 000
Interest and Taxes on Investment (16 500 kw x $155 x 10% x (4+2) years	= 1 534 500
Labor Cost $2000 per year x 6 years	= 12 000
Maintenance $16 500 per year x 6 years	= 99 000
Fuel for 600 hours operation	= 31 000
Total Cost of Gas Turbine	=$6 791 500

require a boiler, boiler auxiliaries, or condenser. Its light weight and compactness minimize foundation requirements, and make possible less expensive buildings.

Since the gas turbine does not need a large water supply, the plant can be placed close to the load it serves. This minimizes investment in transmission facilities and keeps electrical system losses low. These factors assure easy installation and erection, and work to keep invested capital at a minimum. A gas-turbine plant for peaking service can be installed at a capital cost saving of at least 20 to 25 percent compared to a steam plant of the same net output rating.

Operating labor cost of the attended gas-turbine power plant is low. One man per shift can operate a single gas-turbine station; multiple gas-turbine stations can be operated with little increase in manpower. If desired, plants can be built to operate unattended from remote signals. The gas turbine on standby requires no attendance, burns no fuel, and suffers essentially no deterioration. It has the ability to start and pick up load quickly, a characteristic that is especially valuable for meeting peak loads and emergency situations. Since the gas turbine can carry full load within 20 minutes from a cold start, it uses less fuel than a corresponding steam unit during starting periods. Maintenance cost of a gas-turbine power plant is low, due primarily to the relative simplicity of the machine.

A gas turbine has intermittent overload capability. In peaking service it can carry loads 10 to 15 percent above its continuous rating. At low ambient temperatures its maximum capability reaches 150 percent of the nominal rating. In areas of low humidity, spray coolers can be employed to reduce the effective ambient temperature at the gas-turbine inlet. Further increases in maximum capability output of about 30 percent can be obtained by water or steam injection. This provides extra capability without improving cycle efficiency. However, if steam is generated in an exhaust-heat recovery boiler and injected into the gas stream, increased capability is obtained with an additional improvement in efficiency of about 10 percent. A disadvantage of water and steam injection schemes is that pure water must be used to prevent deposits in the turbine. The increase in power obtained by injection methods is limited by the maximum mechanical capability of the machine.

The fuel consumption of a gas-turbine plant without heat-exchange equipment is relatively higher than that of a base-load steam plant. Heat rates range from 18 000 to 19 000 Btu per kwhr at nominal full load, and up to 28 000 Btu per kwhr at 50 percent load. Under cold weather conditions, when air density is high, the output rises well above the normal rating and the heat rate falls to about 16 000 Btu per kwhr.

At present, the gas turbine can operate on natural gas, oil, or treated residual oil. A dual-fuel system can be provided to burn gas or oil, and change fuels under load.

economic examples

The following examples are representative of situations that exist in some phase of the power generation industry. Installed cost and fuel cost vary depending on the geographical location and the specific application.

The installation costs for gas turbines are determined from installations of the 5500-kw Westinghouse gas turbine. Actual installations of air ducting has run $5 to $9 per kilowatt. Electrical accessories are slightly reduced from those required for steam installations and run $10 to $13 per kw. For the examples to follow, this figure has been increased to $18 per kw for a 16 500-kw gas turbine to allow construction

of a building comparable to indoor steam installations. The cost of the comparable size gas-turbine building is much less than the steam plant since the installed kw per cubic foot of building is considerably larger for the gas turbine. As would be expected, installed cost of the 16 500-kw gas turbine is considerably less per kilowatt than the smaller 5500-kw machine. The installed cost figures used in the economic examples are given in Table I.

No attempt has been made to evaluate the outdoor switchyard since no basic difference exists in the yards for comparable size gas and steam turbine stations. However, in the following third example, where a difference in rating exists between the units compared, the outdoor switchyard has been included as indicated.

Example 1—Peaking Plant—Assume that rising peak loads require a capacity addition to the system. A new efficient base-load steam unit can be added in the conventional way, thus decreasing the load factor of older, less efficient units on the system. The least efficient units then run the shortest period of time and carry the peak portion of the load.

The alternative is to add a gas turbine unit to carry peak loads. The gas turbine will have a low load factor, but the existing steam units will have an increased load factor. The gas turbine alternate is expected to have a somewhat lower first cost and annual charges than the steam turbine, but more fuel will be required. Additional fuel is required because the gas turbine has a higher heat rate than the corresponding steam unit, and also because all the existing higher heat rate steam machines must operate at a higher load factor than if the total steam-turbine capacity was increased.

As tabulated in Box A, the total annual saving credited to the gas turbine alternative is $3.81 per kw, or $62 865 for a 16 500-kw machine.

Example 2—End of the Line Plant—The assumed situation is that a remote load can be supplied either by a gas turbine near the load, or by steam-generated 7.0 mill power over a transmission line. The load factor is 50 percent and gas-turbine heat rates must be adjusted to reflect this type of operation. The example tabulated in Box B is based on a 40-mile transmission line at 69 kv, which is able to carry a kva load about equivalent to that of the 16 500-kw gas turbine. The total annual saving credited to the gas turbine is $5.76 per kw, or $95 040 for the 16 500-kw machine.

Of course, the saving effected is dependent on the length of transmission line required. The calculated break-even point falls at a transmission line length slightly over 25 miles.

Example 3—Deferred Investment—In this example, assume that long-range planning indicates need for a large steam plant at a certain location. The first unit would be 100 mw and would be installed some four years in the future. However, local area load requires immediate installation of supporting capacity. If a 16 500-kw gas turbine were installed the first year, and another during the third year, they would meet the local area load needs during the four years. The gas turbines are expected to operate only 100 hours per year. At the end of four years, the 100-mw unit would be installed.

As an alternative, the 100-mw unit and its substation facilities could be installed immediately. The question—is it more economical to put in the large steam unit immediately, or defer the large investment for four years by putting in gas turbines? If the latter alternative is taken, the gas turbines must be written off entirely in four years. If the large steam unit is installed, only fixed charges need be considered because fuel, operating labor, and maintenance charges for such a plant would be balanced by equal reductions else-

TABLE I

INSTALLED COST ESTIMATES $/KW (EXCLUDING OUTDOOR SWITCHYARD)

	Simple Open Cycle Gas Turbine Plant		Steam Turbine Plant		
Item	5 MW	15–20 MW	5 MW	15–20 MW	100 MW
Gas Turbine Generator	130	100			
Steam Turbine Generator			78	52	40
Air Ducts & Stack	9	7			
Boiler Plant Equipment			87	73	57
Structures & Improvements	22	18	39	32	24
Electrical Accessories	13	10	21	18	14
Total	174	135	225	175	135

TABLE II

OPERATING LABOR COST ESTIMATES

Turbine Rating	Operation Hours Per Year	Cost Estimate
5 000 kw Gas Turbine	8 760	$ 40 000
	2 000	16 000
	100	2 000
16 500 kw Gas Turbine	8 760	40 000
	2 000	16 000
	100	2 000
5 000 kw Steam Turbine	8 760	120 000
	2 000	48 000
	100	12 000
16 500 kw Steam Turbine	8 760	120 000
	2 000	48 000
	100	12 000
60 000 kw Steam Turbine	8 760	160 000
	2 000	64 000
	100	16 000

These estimates are based on the assumption that with a 40 hour week, annual vacations, sick leave, etc., it will take five men on the payroll to keep a 24 hour position filled. The labor cost is $4 per hour. For less than continuous operation the cost estimates are based on reduced levels of man power.

TABLE III

MAINTENANCE MATERIAL AND MISCELLANEOUS EXPENSE

Gas Turbines	$3 per installed kw per year for full base load operation $2 per installed kw per year for peaking service $1 per installed kw per year for emergency standby service
Steam Turbines	$3 per installed kw per year regardless of type of operation

TABLE IV

HEAT RATE OF TYPICAL 16 500-KW GAS TURBINE

16 500 Kw Simple Open Cycle		
Percent Load	Output Kw	Heat Rate Btu/Kwhr
100	16 500	18 250
75	12 400	20 100
50	8 250	25 000
25	4 100	39 750

where in the system. The electric substation and transmission system will require reinforcement in proportion to the generating capacity addition in either case. This charge is shown as $20 per kilowatt in Box C. The saving for gas turbines, at the end of four years, is calculated at $2 508 500. In addition, the gas turbines are still available for future peaking or standby service.

combined steam and gas turbine cycles

The maximum attainable efficiency of any thermodynamic cycle is a function of the temperature range the working fluid passes through in traversing the cycle. Most practical power generation cycles have a lower limit close to ambient atmospheric temperature; the highest temperature reached by the working fluid determines attainable cycle efficiency.

A combination of the steam and gas turbine utilizes exhaust heat from the gas turbine in the steam cycle. In the combination steam-gas cycle, there are two working fluids—air and steam. The heat put into these fluids by fuel combustion is converted into useful work at all temperature levels between the gas-turbine inlet temperature of 1450 degrees F and the ambient temperature. The potential gain from using the combined cycle is represented by all energy converted into useful work between 1450 degrees F and the usual throttle steam temperature of 1000 to 1100 degrees F. The percentage of this potential gain actually realized in any given plant is a function of the complexity of the cycle and the detailed design of plant components.

The simplest way of utilizing a gas turbine to raise the overall efficiency of a steam power plant is to drive a piece of plant equipment, such as a boiler feed pump or house generator with a gas turbine and use the hot exhaust gases to heat feed-water, to generate low-pressure steam, or as preheated combustion air to the boiler furnace. This approach results in a two to four percent improvement in plant efficiency.

Although the improvement is modest, several advantages are immediate. In such a combined cycle, the gas turbine and the steam generator retain their individual characteristics and can be operated independently of each other if necessary. The boiler closely resembles the conventional unit in size and construction. The gas turbine is combined with the steam cycle but not fully integrated into it.

The most promising combined steam and gas-turbine cycle, which shows possible reductions in heat rate of 4 to 8 percent, is the pressurized-boiler cycle (Fig. 2). Here, the gas-turbine compressor provides air at about six atmospheres for a pressurized furnace and boiler. Fuel is mixed with compressed air and burned; the hot gases are utilized to generate steam. The gases leave the boiler at 1450 degrees F and are expanded through the turbine element of the gas turbine. The turbine drives the compressors and power-generation equipment. Heat is removed from the turbine exhaust gases at atmospheric pressure, in a regenerator, economizer, and stack-gas cooler. Many variations in this cycle, both in steam equipment and gas turbine arrangements, are possible. Each arrangement has small advantages in heat rates or machinery control requirements for a specific application.

For a large utility, the greatest economic gains can be obtained with a combination of gas turbine and supercritical-pressure steam plant. A calculated comparison between a combined cycle and a straight supercritical steam cycle with a generating capacity of 580 000 kw indicates a 4.2 percent improvement in heat rate in favor of the combined cycle. A comparison of the boiler and feedwater heating systems of these plants is shown in Fig. 3. In the combined cycle, feedwater heaters (numbers 4 and 5 in the diagram) have been replaced with a stack-gas cooler, and the air preheater has been interchanged with the economizer. The boiler operates at six atmospheres with air supplied by the gas-turbine compressor. Turbine power not required to drive the compressor drives a generator and represents 12.4 percent of the net station output of the combined plant. In addition, the combined cycle requires 8 percent less feedwater from the condenser and 17.6 percent less throttle steam flow than the equivalent conventional steam plant.

Air is supplied to the pressurized boiler of the 580 000-kw combined plant at a rate of 3 942 000 pounds per hour by the gas-turbine compressors. The fuel used for the heat-balance studies is coal with a 15 percent ash and 7.5 percent moisture content. The boiler efficiency for burning this type of coal in a conventional plant with a 275-degree F stack temperature is 89.7 percent. Boiler efficiency for the combined cycle is 88.6 percent, based on the same percentage heat losses (moisture content of fuel, completeness of combustion, radiation and heat rejected with ash) with the exception of stack loss, which is based on a 325 degree F exhaust temperature.

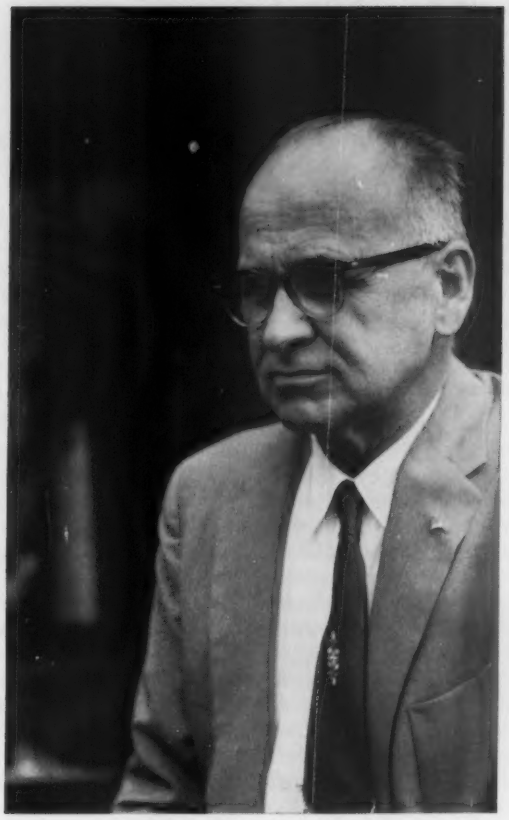
Thermodynamic calculations unquestionably show a large fuel saving for the combined cycle; however, the question of first cost remains. An accurate picture of first cost can only be obtained by actual construction of a combined-cycle plant. The addition of gas turbines increases the number of components, but in general, steam equipment is reduced about 12 percent. A total installed cost of $135 per kw for a 100 000-kw steam plant and a 16 500-kw gas turbine plant, each taken separately, is shown in Table I. In combination the initial investment would probably remain about the same or perhaps decrease; the boiler for a pressurized cycle would be about one-fifth the size of a conventional boiler, and although a pressure vessel, it probably could be built with some economic savings. Consequently a combined-plant, with its large improvement in fuel rate, should be built for the same or fewer dollars per kw than a modern steam plant.

summary of combined cycles

Integration of the gas turbine into the basic steam cycle results in improved heat rates for present day steam cycles. In particular, it offers the greatest improvement in plant heat rates for units under 200 mw capability. The percentage gain in this size range is considerably greater than can be obtained in the larger supercritical pressure machines.

The pressurized-boiler combined plant can presently be operated on natural gas, oil, or treated residual oil; however, application of this cycle will not be widespread until the fuel utilized for the power plant is coal. The primary problem imposed by a coal-burning cycle is blade erosion by fly ash carried through the gas turbine. Based on available data, the engineering problems involved in separating fly ash to an extent necessary to prevent serious erosion and achieve reasonable gas-turbine life are believed capable of solution. A similar problem existed in early application of gas turbines in Houdry process refineries. Sufficient carry-over of carbon and catalyst existed to cause rapid erosion of the gas turbine blades. The introduction of particle-removal equipment into the system virtually eliminated erosion of the turbine blades and resulted in a satisfactory turbine life.

The combined cycle offers a large gain in thermal efficiency and a promise of reasonable first cost. To prove its economic advantages, it will be necessary to build a pilot plant to gain operating experience. Most certainly, the benefits of combined steam and gas turbine cycles need further investigation. ■



BENJAMIN P. BAKER

Early in 1957, *Benjamin P. Baker*, a Consulting Engineer for the Switchgear Apparatus Departments in East Pittsburgh, logged his 100th patent award—and established a strong bid for the reputation as the company's most prolific active inventor. In his 34 years with Westinghouse, Baker has submitted 201 patent disclosures, has been awarded 104 patents, and has 18 active patent applications. In the history of Westinghouse, not more than a dozen men have previously equalled or surpassed this mark. And Baker continues to narrow the field.

All of Baker's patents are in the circuit breaker field, and they cover the area completely. He has worked on circuit breakers in interrupting sizes from 10-amperes up to 25-million kva, and with almost every conceivable arc-interrupting medium—compressed air, magnetic field, oil, sulphur-hexafluoride—even water! Two of Baker's designs have merited special $5000 patent awards from the company, the highest individual patent award the company makes. The first, of which Baker is a co-inventor with Dr. W. M. Leeds, was the multiflow De-ion grid oil circuit breaker, and the second was for his patents on dead-tank compressed-air, high-voltage circuit breakers.

In 1939, Baker's contributions were acknowledged with the Westinghouse Order of Merit, the company's highest award. The citation that accompanied the award read ". . . for his originality in the development of switchgear; for his unique capacity for translating new fundamental discovery into commercial apparatus; for his initiative in the development of the 'corncob' breaker; and for his highly cooperative attitude toward his fellow workers." The last sentence was well chosen; when mention is made of his accomplishments, Baker always insists on giving full credit to his associates.

The word "corncob" in the citation was a special concession. Baker, who comes from a farming family—in fact, has operated his own farm as an avocation for many years—has that intuitive instinct for practicality—he'd probably call it "horse sense." This earthy practicality has even colored his language in describing graphically his engineering achievements. Hence, when the interrupting unit in a porcelain-clad oil circuit breaker he developed resembled a corncob, he called it a corncob—and "Bennie's corncob" it was, to everyone associated with the project.

The practical side in Baker has also given him the ability to work with his hands—and the urge to actively participate up to the elbows in anything he does. When Baker gets an idea, he heads for the shop to direct proceedings. This drive and enthusiasm has proven extremely contagious to his co-workers. Baker often sleeps with a pad of paper and pencil at bedside. He gets by with remarkably little sleep, and when he wakes up in the small hours of the morning, he'll use the time to think out some particular problem. Baker acknowledges that he has done some of his most productive thinking in these early morning hours.

Baker's drive and enthusiasm was initiated at an early age. Growing up on a farm near Winchester, Virginia, Bennie walked 10 miles to and from school each day in addition to helping with the farm chores. Even then, his inventive mind was actively at work. He jokingly tells that his first patentable ideas were conceived at the age of eight.

Baker worked part time to help finance his way through Lebanon Valley College, near Harrisburg, Pennsylvania, and graduated in 1919. A year later, he added a BSEE from the University of Virginia. That summer, he joined the Westinghouse Student Training Course. However, he received and accepted an offer later that same year from the University of Pittsburgh to teach physics and do graduate work.

His association with the company continued during summer vacations, when he worked at the Westinghouse Research Laboratories. By 1924, he decided to give up the teaching profession in favor of applied engineering, and rejoined Westinghouse as a Development Engineer under the guidance of Dr. Joseph Slepian. One of Baker's first major contributions was his work with the Type U De-ion breaker, a magnetic air breaker conceived by Slepian, and the first power breaker of its kind in the 2.5–15-kv class.

Baker's ability to translate fundamental scientific discoveries into workable apparatus was soon recognized, and in 1929, he was transferred to the circuit breaker department of the Switchgear Division. In the early 30's Baker helped develop the arc quenchers (De-ion grids) for oil breakers. This development culminated in the 287-kv oil breaker for Hoover Dam, the first dead-tank oil circuit breaker capable of interrupting short circuits in only 3 cycles at high voltage.

Shortly after this, he left oil breakers to explore the possibilities of a 15-kv, 1500-mva water breaker. However, compressed-air breakers, which he worked with simultaneously, held greater promise, and Baker soon concentrated on air-breaker design.

By 1942, Baker was back on oil breakers, and helped design the multiflow De-ion grid oil circuit breaker, which made possible a 50 percent savings in breaker oil, and therefore much smaller tank designs. His co-patent on this design eventually earned him his first $5000 patent award.

In the development of the 345-kv oil breakers, Baker was part of the development team, and participated particularly on voltage distribution problems in the multi-break interrupter.

By 1954, Baker again concentrated his efforts on compressed air breakers, and helped develop the dead-tank type 138-kv design. His basic patents in this design resulted in his second $5000 special patent award.

Baker is presently concentrating in the newest circuit breaker field, using sulphur-hexafluoride gas for the arc-interrupting medium. However, as a Consulting Engineer for the Switchgear Apparatus Departments, he may be asked to lend a helping hand to develop almost any conceivable piece of switchgear. His associates found long ago that "Bennie" was a big asset to any team effort. Just Baker's enthusiasm for the job he tackles is a stimulant to his associates. One of Baker's friends recalls a typical incident; he was dressed up in his Sunday best, ready to attend an afternoon wedding when some trouble was encountered in an oil breaker. Baker carefully removed his coat, shirt, and trousers and climbed into the oily tank—he wanted to see for himself. This extreme interest in his work makes Baker the inventor and engineer that he is.

COAL . . . a dark mineral with a bright future

Though wood fires preceded it and atomic fission will replace it to some extent, coal still remains king of the energy-producing materials.

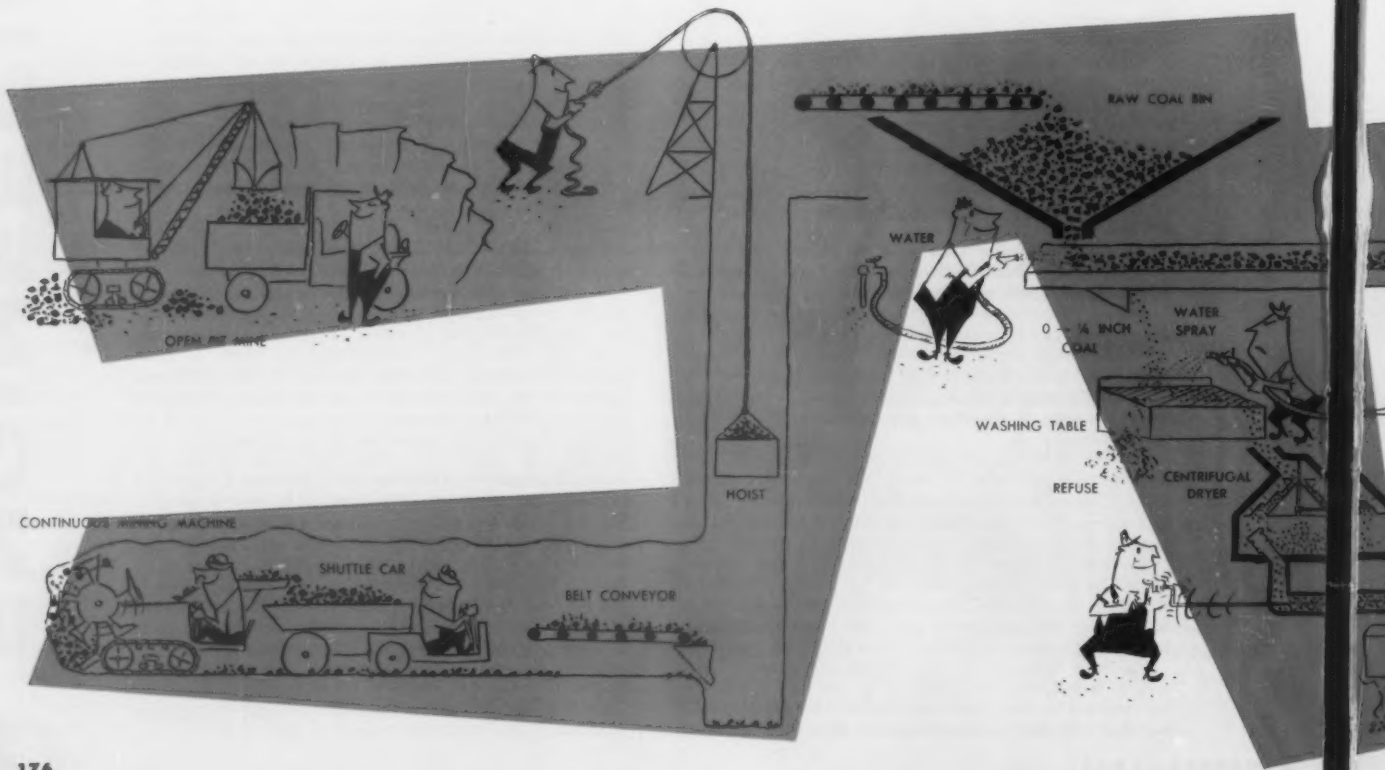
Coal is the most familiar, but perhaps the least appreciated mineral in the world. As an energy source, its use in the production of iron and electricity alone mark it as a major mineral. But added to this are its other fuel applications and many chemical by-products.

Little is known about the first men who perhaps accidently spilled these black rocks on their campfires and watched in amazement as the coal sparked and took fire, but there is strong archeological evidence that people in Wales used coal 3000 years ago. The Greeks first mentioned coal; Theophrastus, a pupil of Aristotle, used the word "anthrakes" in 371 BC. The British, who were the first to mine and use coal on a large scale, appropriately fathered the word coal, which started off as "kohle," grew into "cole" or "colle," and finally changed into its modern form in the 17th century.

Coal was discovered in the United States in 1673 by the French explorers, Louis Joliet and Jacques Marquette, near Utica, Illinois. But over 70 years passed before coal was mined and sold commercially near Richmond, Virginia. Many small mining companies were formed in the 1830's in the Appalachian regions and along the Ohio, Illinois, and Mississippi rivers, but few survived, due to lack of capital, small markets, and inadequate and expensive transportation facilities. The industry did not mine its first million tons until the 1840's; but soon after, the advent of railroads opened up a vast new market for coal and also provided a rapid and extensive transportation system. Since then, coal has helped many industries grow and expand to their present size—electric utility plants, nonexistent 100 years ago, now are the industry's largest single customer.

ranks and types of coal

A large number of categories, each of which still covers much ground, point up the almost endless number of forms in which coal can exist. The familiar names anthracite, bituminous, subbituminous, and lignite are the ranks of coal that classify the mineral according to its moisture, volatile-matter, and heating value. The rank, or degree of coalification, depends not on the age of the coal, but on the earth's pressures exerted during formation. A young coal bed that has been subjected to high pressures due to severe upheavals of the earth's surface has a higher percentage of fixed carbon, making it a higher rank coal than an old bed that was subjected only to the pressure of overlying strata. In general, the higher the fixed-carbon content and the lower the moisture and volatile matter, the higher the rank, except for the lower ranks of subbituminous and lignite where the heating value and caking and weathering properties determine the rank classification. These four ranks are further divided into groups to more accurately pin down the degree of coalification. However, be-



cause the type of fossilized vegetation that constitutes coal greatly affects its use as a fuel, the mineral is further classified according to its constituents.

Anthracite or hard coal, which is most familiar to the home owner, is lustrous, does not soil the hands, and burns with a blue flame. Anthracite is very slightly "banded." These bands contain varying amounts of anthraxylon (woody parts of plants) and attritus (finely divided matter formed from organs of plants such as seeds, pollen, and leaf tissues). The most extensive anthracite fields in the United States are located in eastern Pennsylvania. Although the heating value of anthracite is below that of high-grade bituminous coals, its freedom from smoke and its ability to burn longer without attention make it an ideal domestic fuel. Fine sizes of anthracite are used in great quantity for electric utility and industrial boilers. Anthracite is also mixed with bituminous coal to produce coke.

Bituminous coal is the most plentiful and widely used coal in the country. The Appalachian field, one of the largest bituminous deposits in the country, extends from northwestern Pennsylvania and proceeds southwesterly to central Alabama. Other large deposits are found in Michigan, Illinois, Iowa, Missouri, Oklahoma, and Texas.

Bituminous coal is either burned directly, or converted into coke for smelting iron ore. The banded type of bituminous is the only type used for coke; the other two common types of bituminous, splint and cannel coal, do not usually produce coke when processed in a coke oven. All types of bituminous coal can be used by power plants, railroads, and most heating applications, except for a few applications, such as cement and tile burning, where the noncoking varieties are used because of their high heating value and high proportion of volatile matter. Splint coal is dull gray, hard, and breaks into blocks when taken from the mine. Major applications are in power plants and railroads. Cannel coal, which burns with a long yellow flame, is used mainly as a fireplace fuel, although it is also used to make illuminating gas. Some cannel coals have low firing points and can be ignited with a match.

When bituminous coal is processed to produce coke, many valuable by-products are saved. From one ton of coal, about 1300 pounds of coke, 9 gallons of tar, 20 pounds of ammonium sulphate, 3 pounds of light oil, and about 10 000 cubic feet of coal gas are produced. From these by-products are made, at last count, nearly 200 000 chemical products, ranging from road tars and fertilizers to lipsticks and drugs.

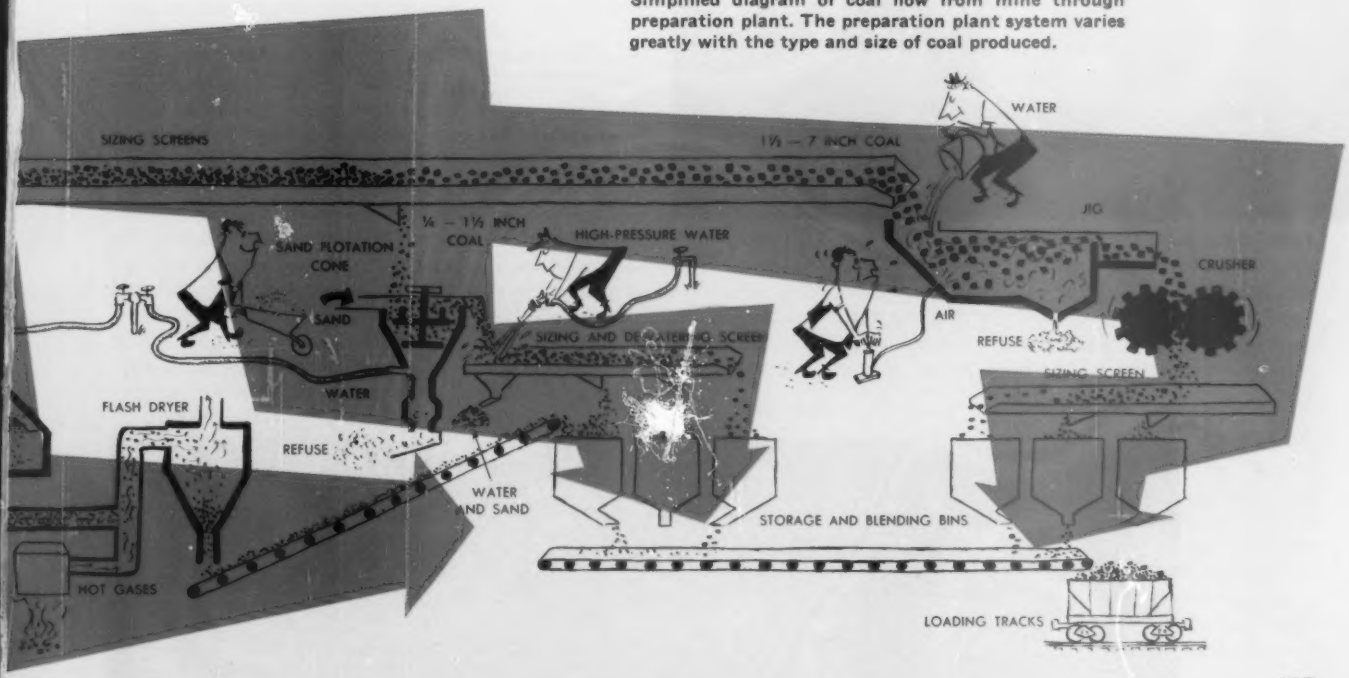
Subbituminous coal appears mostly as a banded coal, but does not yield coke as banded bituminous does. It weathers upon exposure to air and burns spontaneously if not stored properly. The largest fields of subbituminous are found in Montana, Wyoming, Colorado, Arizona, and New Mexico. These fields service principally nearby industries. Subbituminous is used primarily in electric-utility plants and industrial heating applications.

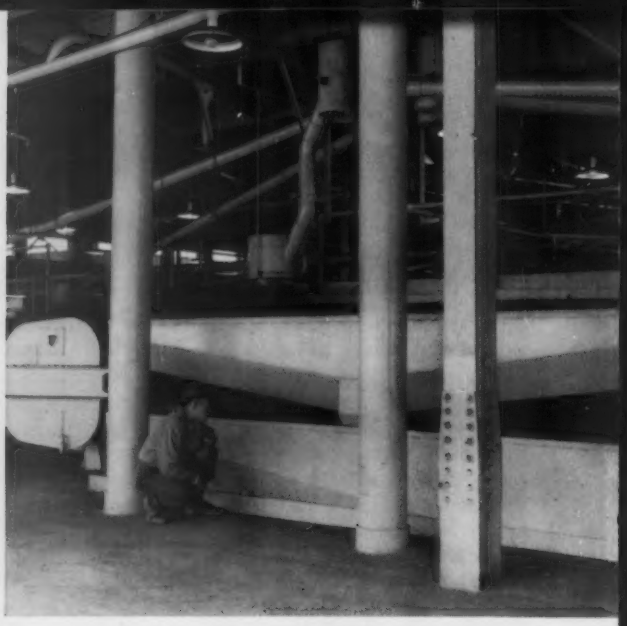
Lignite and brown coal have a light to dark brown dull coloring and are compact. American lignite contains about 30 percent moisture, and its heating value is low. Thus lignite must be dried and briquetted to be shipped economically. An extensive deposit of lignite exists in North Dakota, South Dakota, and Montana, but unfortunately this field is far from the heavily industrialized markets. This low-rank coal is used by utilities and general industry.

the strip mine

When the coal bed lies within 80 to 100 feet of the surface, strip mining is the most practical and economical means of removing the coal. About 22 percent of the coal in the United States is strip mined. This method is claiming an increasing share of the coal market, due mostly to low capital expenses

Simplified diagram of coal flow from mine through preparation plant. The preparation plant system varies greatly with the type and size of coal produced.





Washing tables (**above**) separate fine coal from impurities by utilizing differences in density of pure coal and waste products.

Continuous mining machines (**upper left**) are a far cry from blasting and hand-loading operations in use not long ago.

Huge power shovels (**left**) tear off the overburden from the coal seam and dump it on a "spoil bank."

The coal preparation plant of today (**below**) is highly mechanized and equally efficient.

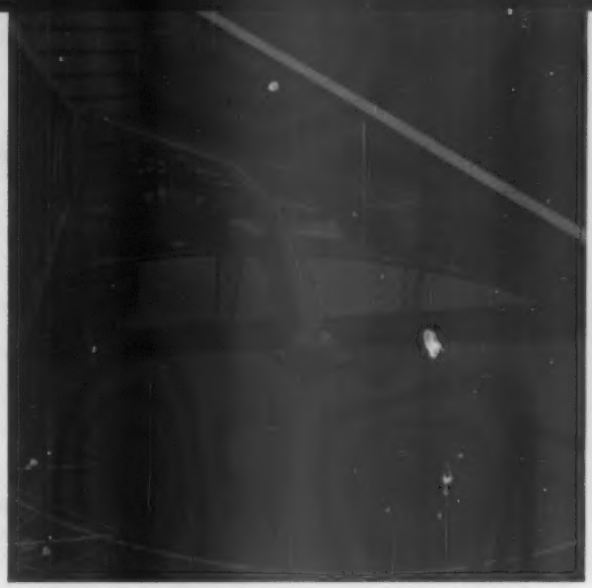
This coal-thickening tank (**facing page**) recovers fine size coals, and also cleans the water so it can be pumped back into the system.

and operating costs, and a large ton-per-man-day output. Yet this method dates back to 1866 when at Danville, Illinois a strip mine was operated with horses, scrapers, and plows.

Today, the overburden covering a coal bed is first loosened by blasting and removed with huge shovels. The overburden is piled on a "spoil bank," laying bare the coal seam. After the surface of the seam is cleaned with scrapers, steel brooms, or bulldozers it is blasted and dug up with smaller shovels.

The demand for coal during World War II rose sharply, and many highway and construction contractors who had equipment laying idle due to war restrictions entered the coal business and started a new type of strip mining—the contour mine. Because at the time there were many deposits of outcrop coal, contour mining was handled with regular highway and construction equipment. After the war contour mining maintained its popularity.

A recent innovation in strip mining is the use of augers where the overburden is too thick for shovels or earth movers. Here a trench is dug to the level of the seam, and augers sometimes 200 feet long bore into the seam and remove the coal. Auger mining can remove up to 65 percent of the coal and is capable of removing 25 tons-per-man-day. In 1956, over 6 million tons of coal were produced by auger mining.



the underground mine

The most familiar and the largest producer of coal in the United States is the underground mine. But the usual image of a miner wielding a pick and shovel is fast becoming history. Today, the underground mine has mechanized machines to remove the coal from the face, load it onto shuttle cars, and convey it to a preparation plant. Depending on the lay of the land, one of three entrances to an underground mine are made. If the area is hilly or mountainous, a level tunnel or drift is run through the hillside, or an inclined entry called a slope is sunk to reach the coal seam. In flat country, a vertical shaft is used.

About 90 percent of the coal in underground mines is removed by the room and pillar method. Here parallel entries or rooms are driven into the coal bed. After the rooms have been mined out, the pillars are removed, starting from the farthest point, allowing the roof to cave in.

Mechanization has greatly increased production in the underground mine. Typical mining equipment in the 1930's consisted of coal-car trains, which for the most part had to be hand loaded. Only a few track-mounted loading machines were available, and these were not flexible in operation. Also the coal faces in thick seams were usually broken down with blasting. Shortly before World War II, the electrically operated shuttle car appeared and was soon followed by a cutting and loading machine. Despite the loss of many men to the armed forces and stringent restrictions on new mining equipment, mechanization pushed coal production to a high of nearly 620 million tons in 1944.

Today continuous mining machines provide flexibility of movement, continuity of operation, and greatly increase production. But the high coal-digging capacity of the continuous mining machine requires a continuous mechanized system to transport the coal to the surface. The mining machine makes use of a ripping, boring, expanding, or vibrating action to continuously break down the coal face. Conveyor equipment carries the broken coal to the rear of the machine and dumps it into an electric shuttle car. When multiple shuttle cars are used in conjunction with a continuous miner, a continuous flow of coal results. The shuttle cars transport the coal to a main conveyor or a coal-mine train. The advent of the continuous miner also brought some disadvantages. When coal was hand-loaded, miners could easily separate dirt and waste materials, but mining machines load everything into the shuttle car, which puts an added load on the coal preparation plant. Also, the mining machine cuts the coal into smaller sizes than blasting and manual picking.

the preparation plant

Methods used in preparing coal for market have changed greatly. The major coal consumers 20 years ago were general industry, railroads, home owners, the steel industry and electric utilities. Because of the heavy demand for large lump and egg sizes, these were sold at a premium price. At this time only large size coals were cleaned—mostly by hand. And for general industry, modified run-of-mine coal was sufficient. But the industrial stokers of today require a uniform size and a cleaner coal. Thus the smaller size coals have to be prepared to the same quality as the larger size coals. Home owners now also demand finer coals, which can be handled by furnace stokers. These changes have put an extremely heavy load on the preparation plant. Where only 61 million tons of coal were mechanically cleaned in 1936, 302 million tons are now cleaned. A preparation plant today can cost as much as the mine it services.

In modern cleaning plants, the incoming coal is broken down by crushers, sized on screens, and washed to remove impurities. Washing tables, flotation cones, dense-medium washers, and jigs are all liquid-type separators that utilize differences in density between the coal and impurities. The density of the liquid in the dense-medium washer can be adjusted so that not only will waste sink and be discarded, but the very pure coal can also be separated from coal with impurities. After washing, the coal is sized again and dried mechanically in whirling drums or in flash dryers. The various size coals are then blended and loaded into coal cars.

reserves

Although coal has been heavily mined in the United States, there are still extensive reserves in the ground. The Federal Geological Survey's circular shows that, assuming 50-percent recovery, the United States has reserves of about 524 729 million tons of bituminous, 231 678 million tons of lignite, 186 467 million tons of subbituminous, and 6996 million tons of anthracite. These reserves plus new techniques in mining and coal preparation assure that coal will play an important part in the nation's industries for years to come. ■

COAL MINE POWER

An integral and vital part of any coal mine or cleaning plant, electrical apparatus—from substations to motors and controls—must be carefully chosen to insure efficient, safe, and economical operation.

A. C. LORDI
Industrial Engineering
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

The nation's industries look to coal for a low cost source of energy. A pound of coal can be used to generate one kilowatthour of electrical energy, or to produce a pound of steel, or four pounds of cement, or a tenth of a pound of aluminum.

The production of coal is increasing and is expected to double by 1975 to one billion tons per year. In doing this, mines are becoming more mechanized and are increasing their use of electrical power. A decade ago six kilowatthours were used to mine a ton of coal; today, twelve kilowatthours are used. With this increase in power utilization, the output of coal has also increased proportionately from six tons per man-day to the present rate of twelve tons per man-day. While motor horsepower varies from fractional-horsepower motors on the flocculant feeder drives in the preparation plant to the 4500-hp m-g set drive motors in the supershovels, the maximum ratings are continuously increasing. Increased dependence upon mechanized equipment and the use of interrelated equipment in continuous processing has placed prime importance on the proper selection of electrical apparatus. To derive the most benefit from electrical power in the coal industry, the equipment used must be safe, reliable, and have a reasonable first cost. And maintenance must not be excessive. These considerations apply with equal importance to the deep mine, strip mine, and the coal preparation plant.

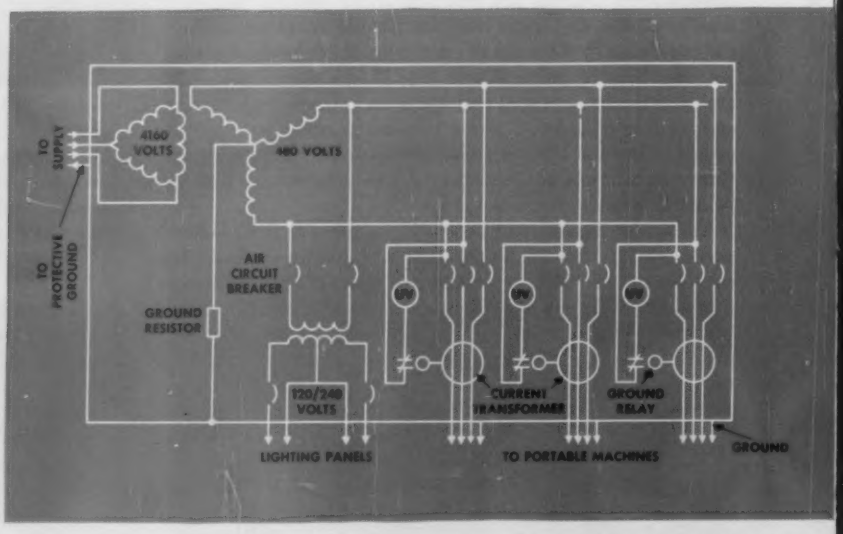
underground mining

About 75 percent of the coal mined in the United States comes from seams 100 to 1000 feet deep. Drills, cutters, loaders, and shuttle cars or conveyors are the machines in a *conventional* mining unit. A continuous miner—a machine that combines the functions of a drill, cutter, and the loader—and shuttle cars or conveyors are the machines used in a *continuous* mining unit. Underground haulage systems, sometimes several miles in length, convey this coal to the surface from these deep mines. These systems, which in a typical mine can move a million tons of coal per year, consist of railroad systems, conveyor systems, or both.

Functional design is the password for all underground coal mining machinery drives. Both motors and controls are explosion-proof, with approval by the U.S. Bureau of Mines required when located in an area with a potential explosion hazard. Space limitations restrict the overall size of equipment; coal seams with a thickness of only 36 inches are continuously mined, and for this, a typical 100-hp motor with its control is less than 24 inches high.

Mining machines have a cyclic load characteristic with severe overload peaks. Underground maintenance at the mining face is difficult and breakdowns are costly. Thus, ruggedness and reliability are also key factors in machine design.

Almost all early mines used rail haulage. The d-c series-wound traction motor best served to power underground locomotives, so extensive d-c trolley systems were installed to feed the d-c power from ignitron rectifiers, m-g sets, or synchronous converters to the haulage equipment. As mines became more mechanized, the d-c distribution system was economically extended to the face machinery with trailing cables. But the magnitude and concentration of electrical loads increased at the most remote points of the power distribution system and continuously moved farther from the power source. Portable track-mounted ignitron rectifiers were developed to move the low-voltage d-c source closer to the load concentrations. The use of heavy m-g sets and



Left—Schematic diagram of a typical mine power center.

Center—2000-kva substation with safety-grounded 4160-volt secondary feeding an underground coal mine.

Right—Continuous mining machines such as this Lee Norse miner boost production in an underground coal mine.

synchronous converters declined. D-c systems at 275 volts, and even at the 550 volts allowed in some states became large. Voltage regulation is often a problem and copper costs can be an appreciable portion of the electrical investment.

The result is an increasing use of a-c power for face machinery and conveyors for underground haulage. The rugged simplicity of the squirrel-cage induction motor is desirable from a maintenance standpoint; and the underground mine power center, lighter, smaller and lower in cost than a-c to d-c conversion equipment also has a maintenance advantage.

In an *a-c mine*, power at a distribution voltage, ranging from 2.4 to 13.8 kv, is carried to the vicinity of the mining face by high-voltage cables. Here, mine power centers transform the distribution voltage to a utilization voltage. The utilization voltage is as high as state laws permit, usually 480 volts a-c. Where a 240-volt a-c limitation exists, the voltage regulation and the required large heavy portable cables discourage the use of a-c power for face machinery.

The underground mine power center consists of an incoming line compartment, a power transformer, and a low-voltage compartment housing air circuit breakers.

The incoming line receptacle serves as a convenient high-voltage cable disconnecting means, allowing the power center to be moved without dragging the cable. Also, cable connectors facilitate sectionalizing of cables. Cable connectors are often electrically interlocked with pilot wires and/or mechanically interlocked by keys with the switchhouse circuit breakers. This interlocking prevents the cable connectors from inadvertently being disconnected while the cable is still energized.

The voltage rating of the primary winding is set by the distribution voltage. A five percent below normal primary tap should be available to compensate for regulation expected at the distribution voltage. The low-voltage winding is usually rated at 480 volts.

The impedance of mine power center transformers is low to minimize voltage regulation. Impedance varies from approximately 3 percent for the 225-kva units to 4.5 percent for the 600-kva units. These low impedances help maintain voltage at the mining machine above 90 percent rated in normal operation, and 80 percent rated during motor starting.

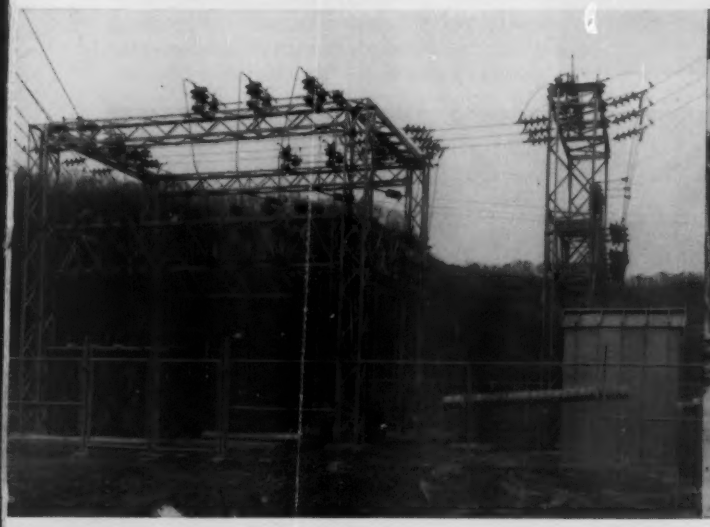
A wye secondary-winding connection is desirable in the mine power center transformer to provide a neutral to safety-ground the utilization-voltage source. A delta winding is required to insure the flow of secondary ground-fault current during ground-fault conditions, and also to minimize third-harmonic voltages. When a delta-wye dual-voltage primary winding is required, the secondary winding is supplied delta-connected, and a zig-zag grounding transformer is used to derive the secondary neutral point for safety-grounding.

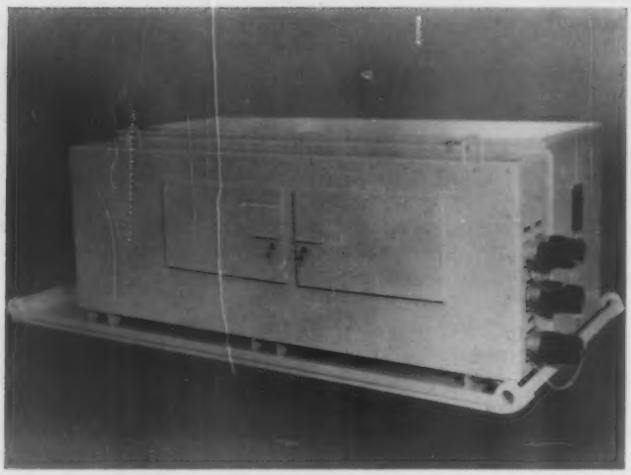
The kva capacity of the power center for a mining unit is based on approximately one kva per connected horsepower. Typical installations use a 225-kva power center for a conventional mining unit and a 300-kva power center for a continuous mining unit.

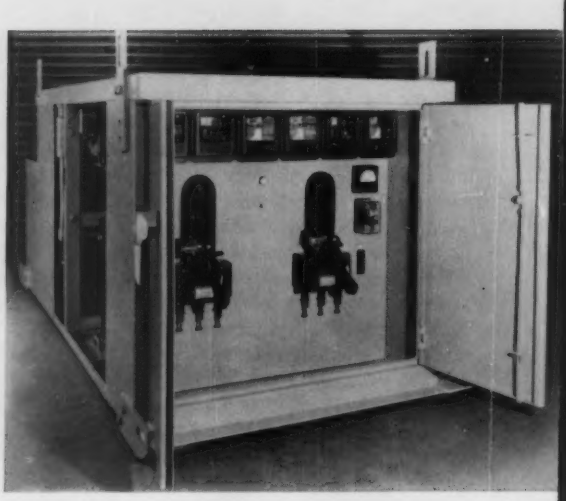
The dry-type transformer eliminates the hazards associated with liquid-filled units. Also, small size and weight are desirable, so class H insulation is usually used to realize maximum kva per cubic inch and pound of power center. Dry-type power center transformer enclosures are available as either ventilated, or as non-ventilated nitrogen-sealed units. The ventilated transformer enclosures are used in mine areas relatively free from rock and coal dust. These units require periodic cleaning with compressed air to remove dust settlement. The nitrogen-sealed transformer compartments are preferred for powering the face-mining equipment, as these units are maintenance free.

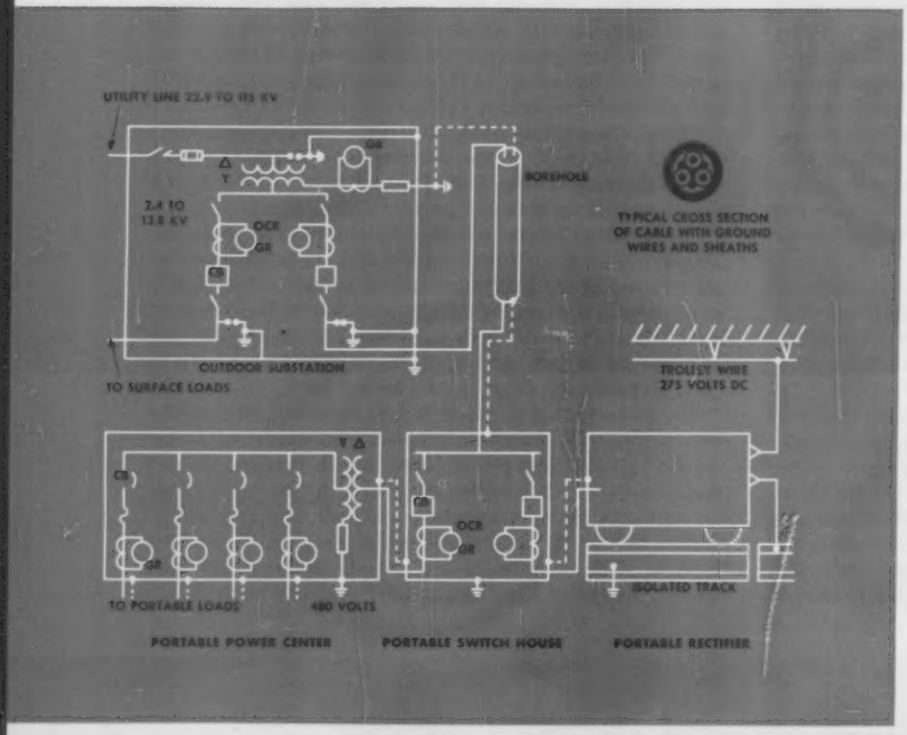
A neutral-grounding resistor limits the line-to-ground fault current, thus limiting portable machine frame-to-ground voltage and fault damage during ground-fault conditions. The neutral resistor is continuously rated to insure its functioning if a ground fault is not immediately isolated. The resistance is chosen to limit frame-to-ground voltage to safe values and yet allow sufficient fault current to flow and be selectively relayed with adequate margin. Grounding resistors are selected to limit ground-fault currents to 25 amperes or less and are used to keep machine frame-to-ground voltages to 15 volts or less during single line-to-ground faults.

The feeder air circuit breakers each have integral thermal- and magnetic-trip units for phase-fault protection. An undervoltage release coil is also included in each breaker. Ground faults down to 3.5 amperes are picked up by the 3-phase balanced-flux current transformer and ground-relay combination to de-energize the undervoltage release coil. This effects fail-safe tripping, even on a double phase-to-ground fault where a source of tripping potential may not be available.









Above—An underground skid-mounted switchhouse.

Upper left—A portable skid-mounted mine power center.

Left—Typical underground mine distribution system.

Bottom—A Jeffrey shuttle car transporting coal from a continuous mining machine to the main haulage system.

The widespread use of the squirrel-cage induction motor in the a-c mine invites power factor penalty costs. To minimize these costs and to realize maximum utility from the cables and transformers, capacitors are used. Capacitors are either built into the power centers or are built as separate skid-mounted capacitor packs. Typical installations are a 90-kvar unit for 225-kva power centers, and a 120-kvar unit for 300-kva power centers.

A good ground inside the mine is difficult to establish and maintain. Thus, the safety neutral-resistance grounded system used at the utilization voltage is also used at the distribution voltage to minimize personnel shock hazard. The ground wires attached to the portable machine frames are carried to the surface and tied to the safety-ground grid for a consistently low ground impedance.

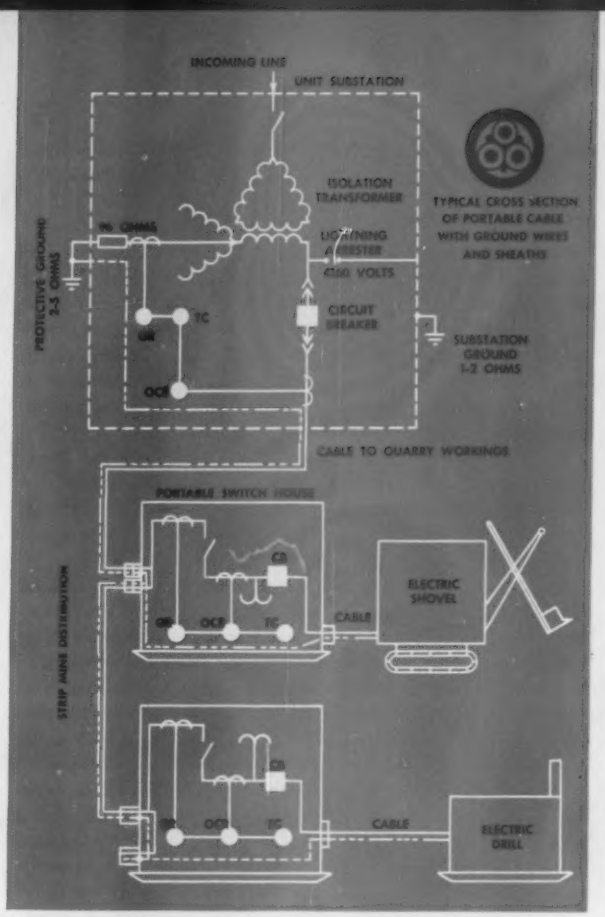
strip mining

The major electrical loads in the strip mine are the large stripping shovels and draglines. Other smaller loads consist of the loading shovels, blast-hole drills, and pumps. The large stripping shovels and draglines are almost universally driven by adjustable-voltage d-c drives. A large m-g set, usually consisting of a synchronous drive motor and three d-c generators, provide easily controlled d-c sources for the mill motors. Both static and rotating regulators are used for accurate current-limit control for the plugging, accelerating, and dynamic braking functions encountered on shovels and draglines. The electric drills and loading shovels require variable speed drives for their operation. Variable speed operation can be realized by mechanical transmissions, eddy current coupling drives and adjustable-voltage d-c drives. Portable pumps are used to remove seepage water from the quarry operation. These pumps are suitably driven by squirrel-cage induction motors.

The total load of a strip mine fluctuates widely as the large shovels bite into the hillside to remove tons of rock and clay that cover the coal seam. Loads may vary from 200 percent motoring to 100 percent generating every minute for an individual shovel operation. The strip mine loads are mobile and are fed by trailing cables. Type SHD portable cables can extend several miles from the substation to feed these loads at a distribution voltage ranging from 2.4 to 7.2 kv. A portable power center is used where low-voltage power at 480 volts is desired for the portable pumps. Here again, the widely varying ground impedance that is characteristic of mines exists in the strip mine. The portable nature of strip-mine equipment necessitates special grounding equipment to maintain personnel safety from shock hazards.

Single line-to-ground faults are limited to a maximum of 25 amperes by a continuously-rated neutral-grounding resistor in the substation-transformer secondary circuit. The neutral-resistor ground is separate from the main-substation ground grid to minimize transient voltages on the safety-ground wire due to primary-ground faults and substation surges. The grounded side of the neutral resistor is connected to the ground wires carried in the interstices of the portable cable fed from the substation secondary circuit. These ground wires connect to the frames of the portable equipment to keep frame-to-ground voltages within safe levels during line-to-ground fault conditions.

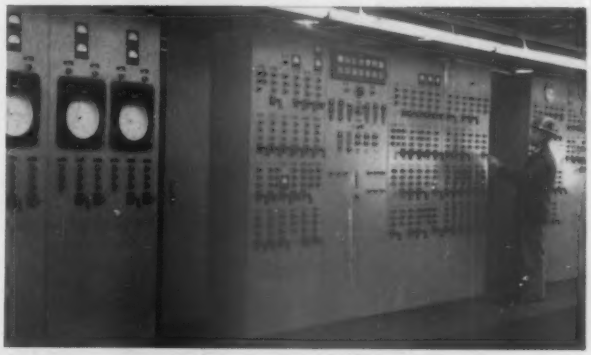
Portable switchhouses serve to provide overcurrent protection for individual shovel feeders. Long-time phase overcurrent relays are chosen to ride over the shovel m-g set motor-accelerating inrush and still provide some cable protection. A sensitive ground relay energized by a balanced-flux,



Top—Typical strip-mine distribution system.

Center—Central control panel in a modern coal-preparation plant.

Bottom—A 200-hp wound-rotor motor driving a raw coal elevating conveyor.



three-phase current transformer detects ground faults down to five amperes and instantaneously isolates ground-faults.

preparation plant

Increasing mechanization in the extraction of coal has also thrown an increasing load on the preparation plant. Mining machines indiscriminately load waste products totaling some 25 percent of mine production which must be separated from the coal in the preparation plant. Also, continuous mining methods have a tendency to produce a larger percentage of fine-coal products, requiring preparation plants to concentrate more and more on fine-coal cleaning.

The present trend toward continuous flow lines and fewer operating personnel requires a careful consideration of the choice of electrical apparatus. The major items of electrical apparatus required in the preparation plant are motors, capacitors, control centers, power centers, and a substation.

Most cleaning plant drives run at constant speed, and for these, the squirrel-cage induction motor is usually satisfactory. The general purpose NEMA-B motor is used within its torque limitations, and on drives that accelerate within 15 seconds. On drives requiring higher starting torques that accelerate within 10 seconds and are not subject to repeated overloads, the NEMA-C motor is used. The NEMA-D motor is preferred on high-inertia crusher drives where repeated overloads are likely to occur. Special consideration is required for centrifugal dryers, centrifugal filters, and large fan drives where long accelerating times are required, but where the load is fairly constant once full speed is attained. A low-slip, high-efficiency NEMA-B motor is preferred, but the excessive rotor heating during acceleration may require special design. Drives requiring accelerating times of over 20 seconds are usually driven by wound-rotor induction motors. Wound-rotor motors are also used on long belt conveyors where allowable belt stresses place limitations on accelerating torques. When used with the resistor-reactor secondary control, the wound-rotor motor has an essentially constant torque characteristic during acceleration. This is especially suited for fast acceleration of long conveyors within belt-stress limitations.

The totally-enclosed, fan-cooled motor is used in dusty and wet locations to prevent the entrance of moisture and dust to the motor windings and bearings. The open dripproof and splashproof motors are used in the cleaner locations.

A choice of motor voltages made on a cost basis alone would dictate that motors 200 hp and above be rated 2300 volts and 250 hp and above be rated 4000 volts in preference to 440 volts. However, other factors also influence the breakpoints in motor voltages. For instance, it may not be desirable to run a high-voltage line to motors in some locations, or to have only a single motor of a given voltage. The higher motor voltages may be preferred where continuity of service requires independence from power centers.

The use of induction motors in the preparation plant results in power factors below 85 percent. To minimize power-factor penalty costs, both synchronous motors and capacitors are used. Power-factor improvement also reduces transformer kva requirements, reduces cable loading, and raises the overall voltage level.

The synchronous motor has the advantage over capacitors in that it supplies increased vars at reduced voltages when most needed. However, synchronous motors do not economically lend themselves to the range of horsepowers and speeds required by cleaning plant drives.

The capacitor bank provides economical, maintenance-free power-factor correction and is preferred in the preparation plant. A capacitor bank at the distribution voltage improves power factor but does nothing to release power center and low-voltage cable capacity. Several small capacitor banks placed near load concentrations are preferred.

Control centers in free standing cubicles are preferred over individually housed control units. The grouped control minimizes engineering and installation costs, enables easy maintenance, and facilitates the interlocking required in modern semi-automatic plants. Combination starters with circuit breakers for each motor control are preferred to quickly and safely isolate faults without the possibility of single phasing.

Current limiting fused high-voltage starters with air-break contactors provide control for the preparation-plant motors that are economically fed at the distribution voltage.

The pushbuttons, meters, indicating lights, and flow diagrams are usually grouped at one operator's panel to allow ready access to controls and to give a visual indication of plant operation with a minimum of personnel.

Several power centers located close to load concentrations provide power at a utilization voltage. This arrangement is preferred over a single power source as it allows a savings in copper, gives better voltage regulation at the machines, and reduces low-voltage circuit-breaker interrupting and momentary current requirements. Power center capacity is chosen on the basis of one kva per connected horsepower.

The ventilated dry-type power-center transformer lends itself well to modern coal cleaning plants where the power centers are located in clean pressurized rooms at an elevated location. Their low weight reduces construction requirements, and the absence of insulating and cooling liquids eliminates the hazards associated with liquid-filled units. Where power centers must be located in a dirty or wet location, the sealed dry-type transformer is preferred or the Inerteen-filled transformer can be used.

When the coal preparation plant receives power at a voltage above 15 kv, an outdoor substation is required to transform the incoming line voltage to a distribution voltage. Initial substation capacity approaches one kva per connected horsepower. A diversity factor of 75 to 85 percent can be realized, permitting addition of loads not considered in the initial planning, and some subsequent expanding of operations. A preliminary estimate of two to four kva per ton per hour of output coal, depending upon the fineness of coal cleaning is sometimes used. The lower figure represents little or no fine-coal cleaning.

The double-ended substation arrangement is preferred over the single-ended substation in modern preparation plants, especially in substation sizes of 5000 kva and above. Replacement of fuses, cleaning of insulators, no-load tap changing, and reduced capacity operation are realized in the double-ended substation without a power outage.

The plant distribution voltage is either 2400 or 4160 volts. The required power is economically distributed at these voltages to power centers with acceptable voltage regulation and power loss. These voltages are also economical for large-motor operation. The 4160-volt system is more favorable to voltage regulation, future expansion, cable and circuit-breaker costs, and copper losses.

The continuous satisfactory operation of coal producing equipment depends upon the electrical apparatus. A careful selection of the distribution and drive apparatus is an economic necessity. The small additional expense for the safety features available, the margin of capacity, and the good voltage regulation designed into the electrical system is easily justified by safer, more dependable performance. ■

MODERN AUTOMATIC DISPATCHING SYSTEM . . . a new tool for improved system economies

All controls and instruments necessary to the dispatcher are mounted in the dispatcher's console.

This modern automatic dispatching system for electric utilities makes possible improved system economies, new operating features, and freedom from dispatching problems.

R. L. TREMAINE **M. J. BROWN**
Assembled Switchgear & Devices Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

No longer does the term *automatic dispatching* mean simply an automatic means of matching generation to load and controlling frequency. Today, economics has become an integral part of the modern automatic dispatching system; the automatic dispatching system must not only control net interchange and hold frequency, but as an integral part of the control it must load all individual machines in the system to reduce the power generation cost to a minimum. Economic loading of machines must be continuous and accurate if maximum economy is to be achieved.

A great deal has been learned in recent years about the economic laws that govern the cost of power generation. This work has lead to an understanding of how system machines should be controlled to reduce the cost of power generation. For the power production cost to be a minimum, all system generating sources must be continuously dispatched so that the cost of the next increment of power delivered to the load is the same from any machine. This requirement must be satisfied regardless of machine location; hence, the incremental cost of transmission losses associated with delivering power from any station to the load must be continuously and accurately computed to achieve maximum economy.[1]

System dispatchers have spent countless tedious hours determining distribution of generation for different system conditions. Transmission costs should be included in such computations, but without modern computing facilities, only educated guesses of these costs can be made. When methods for including transmission losses were developed, the mathematics of the problem proved so complicated that this new knowledge could not be used without special-purpose computers.

economic dispatch computer forerunner of modern automatic dispatching

The development of the Economic Dispatch Computer gave the system dispatcher an invaluable tool for determining

machine loading to achieve minimum cost of system power generation. Experience with these computers proved the value of automatic computation in improving system economies. For example, the savings realized from the West Penn Electric Economic Dispatch Computer are reported to be about $50 000 per year.[2]

Because the Economic Dispatch Computer could determine the load to be carried on each station under any normal system condition, it was natural to think of the Economic Dispatch Computer as a means for controlling existing equipment for matching generation to load in such a manner that economic dispatch could also be achieved. The Economic Dispatch Computer is still very useful for this function where such load-frequency control dispatching systems exist, but in a modern automatic dispatching system it is no longer required.

The Economic Dispatch Computer will continue to be a valuable tool even though its function of controlling a load-frequency type dispatching system has been superseded by the modern automatic dispatching system. It can determine the worth of power at any tie point, which allows important savings in contracting for oncoming power transactions. Accurate calculations of the increase in the cost of power due to taking machines out of service for maintenance can be made. The average worth of power at any tie point can be determined for past or future conditions for billing purposes. The average worth of power from individual machines can be determined, enabling the dispatcher to determine more accurately which machines should be used.

the modern automatic dispatching system

The requirements of the modern automatic dispatching system are many. Not only must it perform functions of existing dispatching systems—control frequency and swings, match generation to load, and include economic dispatch as an integral part of the control—but it must also overcome the shortcomings and have improved features over present systems. For instance, the fact that station swing capability varies has long been recognized; but it is now necessary to recognize that swing capabilities of individual machines within a station also vary. The modern system must be able to correct for major system disturbances automatically without manual assistance, either during the disturbance or afterwards. It must recognize that the shape of machine incremental cost curves vary rather frequently due to machine condition and cooling-water temperature. The dispatching system must be able to utilize the maximum capability of all machines in the system if necessary to correct for major system disturbances. Misunderstandings between a station operator and the system dispatcher, or an error on the part of either should not cause the system to go out of economic dispatch or endanger machine safety by causing load swings in excess of machine capability. The possibility of a higher degree of station automation than is currently in practice must be allowed for by the dispatching system. The dispatcher's problems must be drastically reduced so that he can devote time to more important functions, such as contracting for future power exchanges. Naturally, reliable fail-safe operation must be built into the dispatching equipment.

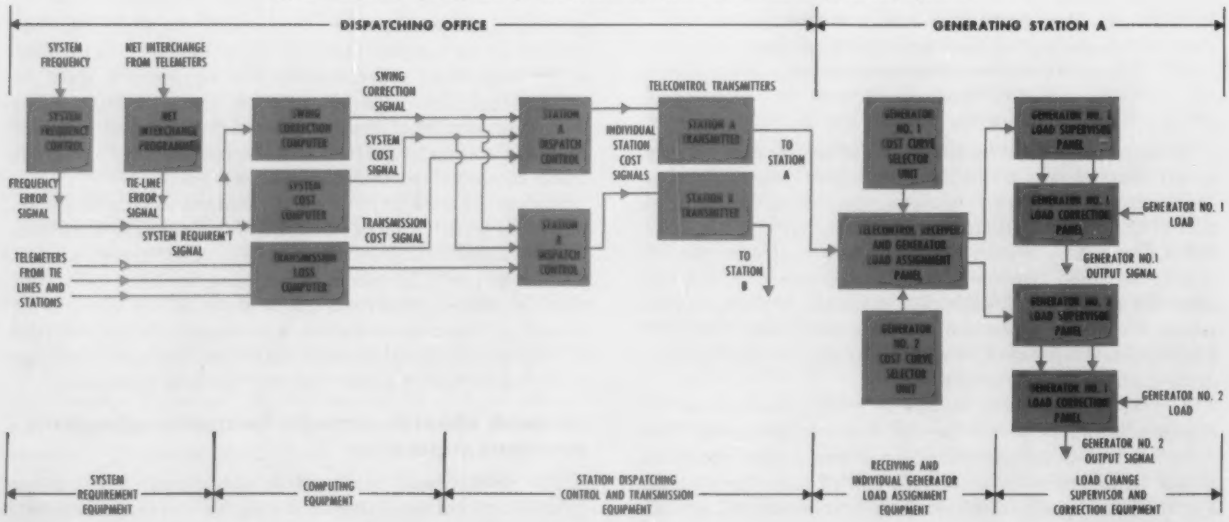
automatic dispatching system

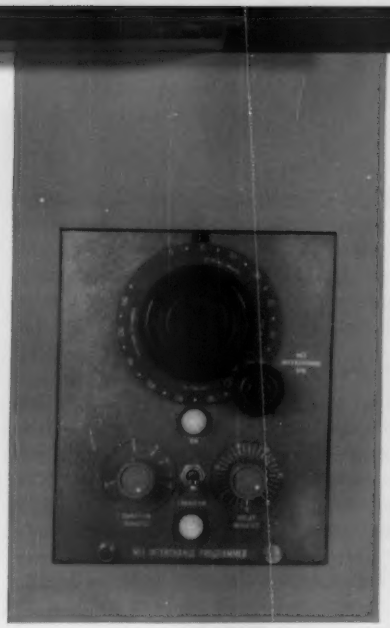
Modern automatic dispatching as accomplished by the Westinghouse system is shown schematically in the block diagram of Fig. 1.

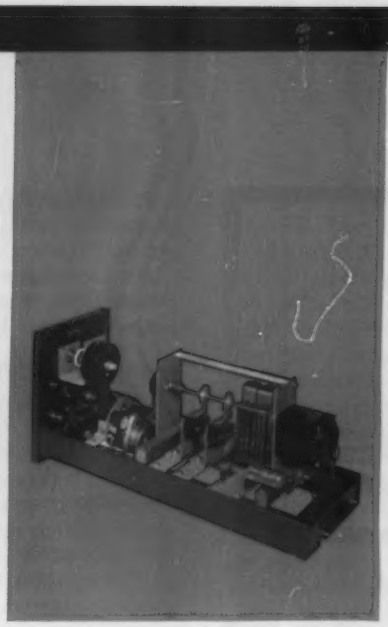
The first function of the dispatching equipment is to determine continuously whether generation should be raised or lowered, and if so how much. To make this determination, two items of information are required—*system frequency* and *net tie-line interchange*. These two values are compared with the desired values of system frequency and net interchange, and their weighted sum supplied to the computing equipment. The computing equipment uses this signal to determine generation changes required to control swing, and to calculate the incremental cost of delivered power. This cost, called *Lambda*, must be accurate regardless of system operating conditions. To continuously calculate transmission losses, a transmission-loss computer is required. This is the computer originally developed for the Westinghouse Economic Dispatch Computer.

At this point, all the information necessary to keep the system in exact economic dispatch and, at the same time control momentary swings, is available. Next, values for individual stations must be computed. Lambda minus the incremental transmission losses associated with a particular station determines its bus-bar cost; to this value the station's

Fig. 1—Schematic diagram of the Westinghouse automatic dispatching system.


DISPATCHING OFFICE
GENERATING STATION A
SYSTEM FREQUENCY
NET INTERCHANGE FROM TELEMETERS
SWING CORRECTION SIGNAL
TELECONTROL TRANSMITTERS
SYSTEM FREQUENCY CONTROL
NET INTERCHANGE PROGRAMMER
SWING CORRECTION COMPUTER
STATION A DISPATCH CONTROL
STATION A TRANSMITTER
GENERATOR NO. 1 COST CURVE SELECTOR UNIT
GENERATOR NO. 1 LOAD SUPERVISOR PANEL
SYSTEM COST SIGNAL
INDIVIDUAL STATION COST SIGNALS
TO STATION A
FREQUENCY ERROR SIGNAL
TIE-LINE ERROR SIGNAL
SYSTEM COST COMPUTER
STATION B DISPATCH CONTROL
STATION B TRANSMITTER
GENERATOR NO. 1 LOAD CORRECTION PANEL
GENERATOR NO. 1 LOAD
SYSTEM REQUIREM'T SIGNAL
TRANSMISSION COST SIGNAL
TELEMETERS FROM TIE LINES AND STATIONS
TRANSMISSION LOSS COMPUTER
TO STATION B
TELECONTROL TRANSMITTERS AND GENERATOR LOAD ASSIGNMENT PANEL
GENERATOR NO.1 OUTPUT SIGNAL
GENERATOR NO. 2 COST CURVE SELECTOR UNIT
GENERATOR NO. 2 LOAD SUPERVISOR PANEL
GENERATOR NO. 1 LOAD CORRECTION PANEL
GENERATOR NO. 2 LOAD
GENERATOR NO. 2 OUTPUT SIGNAL
SYSTEM REQUIREMENT EQUIPMENT
COMPUTING EQUIPMENT
STATION DISPATCHING CONTROL AND TRANSMISSION EQUIPMENT
RECEIVING AND INDIVIDUAL GENERATOR LOAD ASSIGNMENT EQUIPMENT
LOAD CHANGE SUPERVISOR AND CORRECTION EQUIPMENT





Front and inside view of a typical drawer of the dispatcher's console.

Station dispatcher's controls are located on this station control console.

portion of swing is added. These computations are made by the individual station controls. The combined signal is then supplied to the telecontrol transmitter, which sends it over any normally available channel to the individual stations.

The telecontrol signal is received at each station, where it is interpreted in terms of the power to be carried on each machine. Individual machine assignments are supervised to insure that a machine is not called upon to change load in excess of capability. The governor motor responds to these signals, adjusting generation to the value of power assigned.

dispatching-office equipment

All controls that the dispatcher may have occasion to adjust, and the instruments useful to him are mounted in the dispatcher's console, which is mounted adjacent to the dispatcher's desk. The remainder of the equipment is mounted in separate cabinets.

Area-Requirement Equipment—Frequency deviation is converted to a voltage that is proportional to the difference between system frequency and desired frequency. Desired system frequency is normally 60 cycles, but to correct for time, it is frequently necessary to deviate slightly from this value. The *frequency deviation unit* supplies a voltage proportional to the difference between desired and actual system frequency, which is corrected for frequency bias.

The net interchange error is determined by comparing desired net interchange with actual net interchange. Smoothly changing from one level of net interchange to another requires time-consuming coordination between dispatchers of neighboring systems. The *net interchange programmer* is designed to automatically handle this function. The dispatcher sets the time when the next change is to begin, the rate of change, and the final value of the new interchange. A smooth change from one level of interchange to another is accomplished on schedule and at a rate agreeable to all parties in the interchange.

System Computation Equipment—System requirement—the combined signal of frequency deviation and net interchange error—is received by the *system swing computer* and the *system cost computer*. The swing computer is basically an amplifier with an output proportional to area requirement. For a major system disturbance, the swing computer can put out a large signal to insure that the maximum capability of the machines on the system can be utilized if needed. Since the system-requirement signal contains frequencies above the response capability of machines, some filtering action intentionally takes place in this device. It has an adjustable dead band so that minor swings can be ignored if desired. These features contribute to reducing unnecessary generator governor wear. The output of the swing computer is supplied to the individual *station dispatch controls* for transmission to the individual generating stations.

Computation of Lambda—the incremental cost of delivered power—is accomplished by the system cost computer. This device is a slow acting servo whose output is the time integral of the system-requirement signal. It operates slowly because the cost computer need only change its signal as fast as the value of system Lambda changes during the day. It is extremely sensitive to low values of system requirement, and will gradually creep up or down until the system-requirement signal goes to zero thus bringing the entire system into exact economic dispatch.

The development of the system cost computer has allowed the elimination of the Economic Dispatch Computer as a component part of the modern automatic dispatching system. This has greatly simplified the system, improved reliability, and eliminated the need for duplicate cost curves in the dispatching office.

Automatic computation of Lambda is relatively simple. To illustrate, assume that at a given moment the value of Lambda should be lowered. As a consequence, individual stations are receiving bus-bar costs that are too high, and generating power in excess of system need. This power excess causes the net interchange and/or system frequency to be too high. This condition is detected immediately by the system-requirement equipment, which then supplies a signal to the computing equipment asking for a decrease in generation. This information is passed to the machines immediately by the swing computer. At the same time the cost computer slowly lowers the value of Lambda. This causes bus-bar costs to be gradually lowered, which in turn lowers economically assigned power. The system reaches equilibrium when the bus-bar costs transmitted to the stations are such that the total value of generation exactly equals the load, and system requirement is zero.

Tie-line and station powers are available in the dispatching

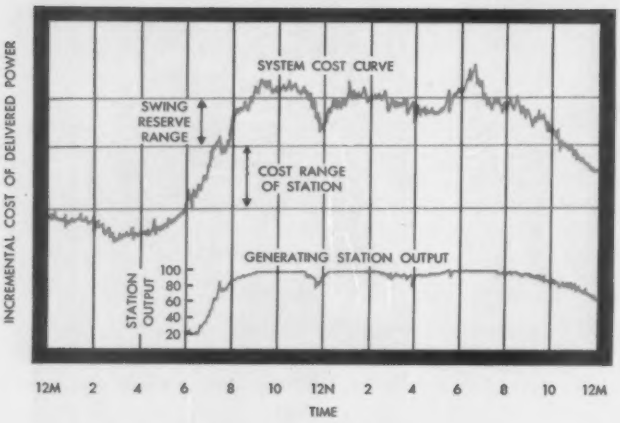


Fig. 2—Power generation curve of an intermediate-cost station during a daily load cycle.

office for the dispatcher's use. These values and Lambda, as determined by the cost computer, are supplied to the "B" coefficient matrix in the *transmission loss computer*. The transmission loss computer supplies voltages that are proportional to the incremental cost of transmission losses for each individual station.

Station-control equipment—Voltages proportional to swing, Lambda, and incremental transmission loss for a particular station are supplied to its *station dispatch control*. This provides the dispatcher with complete control of the station, although under normal operating conditions no readjustment need be made during the daily load cycle. Adjustments for minimum and maximum cost, swing participation, and cost range are provided.

To illustrate the use of this control, an intermediate cost station will be assumed, with a cost range shown in Fig. 2. The swing capability of this station is to be used before it becomes economical in the morning and during the system peak. The operator brings the station machines up to minimum load and puts them on automatic control. The dispatching system then controls station output until the machines are taken off the line in the evening.

By setting the *minimum cost control* at the minimum cost for the station, positive swings are sent to the station, and the machines take positive swings even though they remain at minimum base load. As soon as the station becomes economical, it is picked up automatically and held in economic dispatch throughout its cost range as shown.

To hold swing reserve in the station, the *maximum cost control* is set just below the maximum cost for the station. Under this condition, the station deviates from economic dispatch to provide swing control. If this swing control is not needed during the entire system peak, the cost sent to the station can be biased so that it ignores swing when bus-bar cost exceeds a certain value.

Occasionally system operating requirements require that a station be taken out of economic dispatch. If the dispatcher wishes to increase the load carried by a station at any time, the setting of the *minimum cost control* is increased until the station has the desired output. Conversely, to decrease output, the maximum cost adjustment setting is lowered. To keep the station at constant load, the maximum cost is set equal to minimum cost. The swing participation of a particular station may be increased or decreased to meet abnormal conditions. The *cost range adjustment* on the station dispatch control is used to adjust for fuel cost changes. The output of the station dispatch control is supplied to the *telecontrol transmitter*, where the signal is converted to a form that can be transmitted over the channel. The channel can be any conventional telemetering channel such as microwave, power-line carrier, leased-line circuits, or private wire.

generating station equipment

The continuous signal received by the station can be easily monitored. Should the channel fail, station output remains constant at the last value received unless manually changed. When the channel is restored, the operator immedately receives information telling him to raise or lower generation to bring the station back into economic dispatch. No resynchronizing is required.

Controls and instruments that the station operator may wish to observe or operate are mounted in a console; the remainder of the equipment is in cabinets.

Load Assignment Equipment—The base load that should be carried by an individual station is determined by the bus-bar cost component of the received signal. The load-assignment servo, which ignores swings, turns its shaft in a direction to increase or decrease base load, depending upon whether the received signal calls for a higher or lower bus-bar cost. Tapped potentiometers, one for each machine, are mounted on this shaft. Ten selected points on each machine potentiometer are connected to the ten-point cost curves associated with the particular machine. Six cost curves for each machine, readily selectable by means of a selector switch, are mounted in the generator control equipment. These cost curves are fixed resistors whose values represent the incremental heat-rate curve of the machine. Since shaft position is a function of bus-bar cost, a voltage proportional to base-load assignment for each machine can be obtained directly from the cost cards. The station receives a combined signal consisting of base-load assignment and swing, but the output of the load assignment servo is only base load. Therefore the received signal can be easily compared with the output of this device and the difference is obviously swing. This signal, which is the reconstructed swing, is supplied to the generator control equipment, where it is combined with the base-load assignment signal to determine the power carried by each machine.

Generator Control Equipment—Complete control of each machine is available to the operator. The desired cost curve can be selected by a selector switch. Lamps indicate that the machine is continuously under automatic control. Maximum and minimum kilowatt limits are provided. The minimum limit is set at the level of power corresponding to the minimum load of the machine. The maximum limit is set at the maximum kilowatt output desired from the machine under normal conditions. Provision for manual control of the load to be carried by the machine is provided. In addition, the instrument on this drawer indicates the load to be carried on the machine as determined by the load assignment equipment.

Generator Load Supervision Equipment—Because the modern automatic dispatching system must be able to use the maximum capability of the system machines to recover from major system disturbances, limits on the swings carried by individual machines cannot be imposed in the dispatching office. A device that knows exactly what load changes an individual machine has been called upon to make is necessary so that, at any time, the capability of the machine to accommodate a change in load is known. This is the function of the *load supervisor equipment*. This device is basically a memory circuit, which remembers what the machine did before and

knows what it can do at the moment. By having one of these devices for each machine, the maximum capability of the entire system can be utilized to accommodate major system disturbances without damaging individual machines.

As shown in the schematic (Fig. 1), the load supervision equipment recognizes generator load electrically, not as turbine valve position. By comparing the load assigned with load carried by the machine, a signal proportional to desired load change is produced. This signal is supplied to the load correction equipment.

Load Correction Equipment—The load correction equipment generates signals of correct polarity and magnitude to make desired load changes. A timed repetition rate, variable-duration pulse system is used. Turbine generators, particularly reheat machines, have a relatively long response time, which causes an appreciable delay between the operation of the governor motor to change valve position and actual change in generator output. To eliminate overshoot, the response time of the turbine generator set determines pulse repetition rate. The duration of pulses sent to the governor motor is a function of the magnitude of desired load changes.

additional features of the Westinghouse automatic dispatching system

Only those components necessary to a modern automatic dispatching system have been discussed. The building-block concept is used throughout, so that simpler systems can be used if desired. For instance, if transmission losses are negligible, the components that compute transmission losses can be omitted and the operation of the entire system remains unchanged except for the deletion of this function. No change is required in the remaining components. Frequency can be disregarded if desired. If swing control is not required, those components that perform this function can be eliminated without otherwise affecting the performance of the equipment.

Manual Cost Control—Temporary conditions might require that the system be dispatched manually. Provision for manual control is provided by the system manual cost control. This control is equipped with an instrument which normally indicates Lambda. To transfer to manual control, the dispatcher turns the selector switch to the *transfer* position, at which time the instrument is alternately connected between the output of the *system cost computer* and the *system manual cost control*. The dispatcher varies the manual cost setting until this instrument no longer fluctuates. At this point he can safely transfer to manual operation. To return to automatic operation, the dispatcher again sets the selector switch in the transfer position and raises or lowers the output of the system cost computer until the instrument no longer fluctuates, at which time he can transfer to automatic operation.

Manual Control of Older Machines—Erroneous dispatch of older manually controlled machines can adversely affect system economics. Readouts of the loads to be carried on these machines can be provided in either the dispatcher's office or in the stations. With this information, older machines can be manually held in economic dispatch during system peaks using relatively little equipment.

Bus-Bar Cost and Tie-Line Worth of Power Indicator—In checking to determine if increments of power have been contracted for at advantageous rates, and thus achieving a further increase in system economy, it is frequently useful to have an indication of the worth of incremental power at tie points. This is accomplished by a readout instrument, which receives Lambda and the value of the incremental transmission losses associated with each tie and indicates the incremental worth of power at tie points. A selector switch is provided so that the dispatcher can switch from one tie point to the next and read directly the incremental worth of power at each point.

The worth-of-power indicating instrument can be extended to indicate bus-bar cost at any station by providing additional points on the selector switch. With this instrument, the dispatcher can read directly the incremental bus-bar cost associated with each of the older stations that have manually regulated machines. The dispatcher can determine the powers to be carried on these older machines by reading the values off their cost curves. This information can be telephoned to the station operators.

Additonal Indications in the Dispatcher's Office—Frequently, other indications not required by the dispatching equipment are useful to the dispatcher and hence are most conveniently located on the dispatching console. Such indications are total system generation, net interchange, deviation from net interchange, and magnitude of area requirement. Other indications can be provided if necessary, by adding the necessary instruments to the dispatching console.

Graphic recorders can be readily added to the equipment in the dispatcher's office. In this connection, it must be remembered that only those values desired for historical purposes or to indicate trend need be recorded.

fail-safe operation

Reliability in a control system is directly related to the reliability of individual components. The use of high-reliability components assures system reliability. In such a system, external influences, which are outside of the control of the designer, become the dominant factor responsible for system incapacitation. To meet this situation, the designer must include protection against malfunction when abnormal conditions exist, and therefore must include components to assure fail-safe operation.

In some cases, the Westinghouse automatic dispatching system uses differential methods to get fail-safe operation—slide wires are balanced differentially against slide wires, swing operation is balanced differentially against base-load operation. In other cases, continuous supervisory signals are maintained in the equipment. For example, the variable-frequency telecontrol signal continuously supervises its own channel, and the Lambda analog current continuously supervises station dispatch equipment. Abnormalities sensed by the fail-safe equipment lock out the automatic functions and the equipment reverts to manual control.

conclusion

Modern automatic dispatching has placed in the hands of the system operator new concepts in the field of improved system economies, important new operating features, and a new freedom from dispatching problems formerly requiring manual operation. True economic dispatch 24 hours a day has been achieved. No longer can a system be considered to have an adequate dispatching system unless its system meets the many requirements stated previously. Actual dispatch of a system can be a completely automatic process requiring no adjustments throughout the day for normal system conditions. This portion of the dispatching problem should no longer occupy a high percentage of the system dispatcher's time. ■

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NEW MATERIALS TO CONVERT HEAT TO ELECTRICITY

Research scientists have discovered a new essentially unexplored class of materials that can convert the heat of a burning fuel, or other high-temperature source of heat, directly into electricity (see photo at right). These thermoelectric materials produce electricity simply, silently, and with no moving parts. Because of the potential importance of its practical applications, this method of electric power generation is the object of intense scientific research.

To be useful for power generation, a thermoelectric material must operate at the elevated temperatures encountered in a burning fuel, nuclear reactor, or other primary source of heat, and make the heat-to-electricity conversion with efficiency.

For many years the thermoelectric effect has been observed in metals, most of which easily withstand the required temperatures. But because they are good conductors of heat and electricity their maximum thermoelectric efficiency is about one percent—far too low for power purposes.

More recently, the thermoelectric effect has been found in semiconductors—the class of materials so widely used in making transistors and other solid state devices. Certain semiconductors exhibit reasonable thermoelectric efficiencies, but not at the elevated temperatures at which power is generated.

WHAT'S NEW IN ENGINEERING

The new thermoelectric materials discovered by Westinghouse research scientists are in the general category of substances that characteristically are insulators, or nonconductors of electricity. These thermoelectric materials are ceramics and can be technically described as mixed-valence compounds of the transition metals. The transition metals are a group lying near the center of the natural table of elements and include such common examples as iron, nickel, and manganese. In contrast to solid-state materials heretofore proposed for thermoelectric power generation, the new compounds are inexpensive, easily available, simple to prepare, and not composed of critical elements in short supply.

These ceramic-type materials are thought to be the first solid-state thermoelectric substances to operate at promising efficiencies at temperatures in the range of 2000 to 3000 degrees F. Being ceramics, they are inherently stable and chemically inactive, even at very high temperatures. They can be heated indefinitely in air with an open flame without deterioration; they do not require chemical preparation to an extreme degree of ultra-purity; their use raises no technological problems of high-vacuum operation, or complex electrical or electronic apparatus.

The work with these new thermoelectric materials is still in its early stages, and they do not exhibit the efficiency demanded by conventional methods of power generation. However, for specialized applications, where compactness, light weight and simplicity are more important than efficiency, these new thermoelectric materials offer promise for practical applications requiring small quantities of electric power. ■

NEW INSTRUMENT FOR MAGNETIC STUDIES

Acquiring fundamental data on new magnetic materials often means that special instruments, rarely available commercially, must be designed in the laboratory. One such instrument is a remote-controlled "torque magnetometer"—used to measure characteristics of magnetic materials exposed to a radioactive source.

The instrument is used by Westinghouse materials engineers to measure and record the torque exerted on a thin disk of magnetic material suspended in the gap of an electromagnet (see photo at right). The studies are being made to determine the effects of radiation on magnetic properties of materials. As the sample of material is rotated, the torque exerted on the disk changes according to the change in magnetization of the material. This is measured by the torque magnetometer and automatically plotted on a strip chart recorder. The result is a curve of torque versus angular position of the disk with respect to the direction of the applied field. The information can then be used to determine the *anisotropy constants* of the material—numbers that are simply a measure of the ease with which a material can be magnetized in a certain direction.

Besides being used to study radiation damage to magnetic materials, the torque magnetometer has been used to determine magnetic anisotropy for single crystals of magnetic alloys, and to determine the orientation of grain-oriented magnetic sheet material.

The work that led to the development of the remote-controlled torque magnetometer was done under a Westinghouse contract with the Aeronautical Research Laboratory of Wright Air Development Center. ■

ELECTRONIC REFRIGERATION

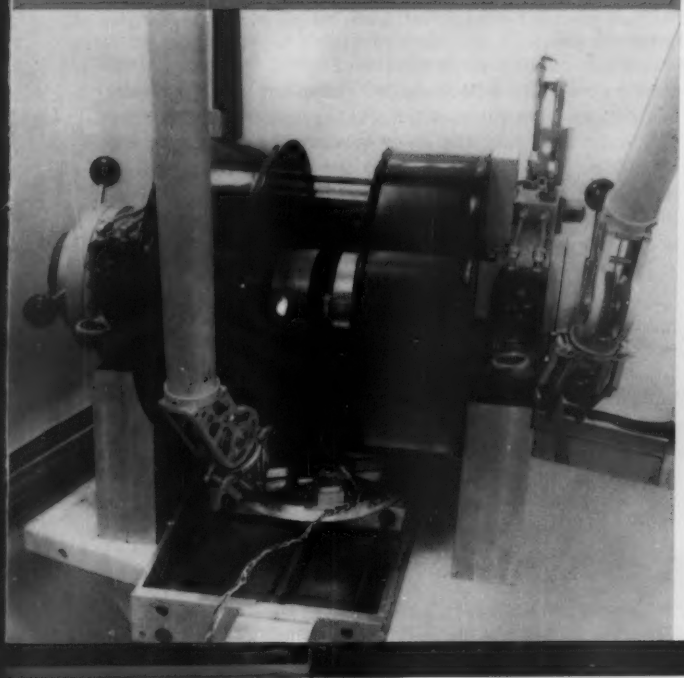
Electronic refrigeration, up to now a laboratory curiosity, has moved into the realm of practicality. To illustrate the principle—refrigeration using no moving parts—a device that can automatically cool or heat a baby's bottle and a mobile hostess cart with both refrigeration and oven compartments were designed by Westinghouse engineers (see photos on p. 192). The devices are a practical application of the cooling principle first discovered by the Frenchman, Peltier, in 1834: When a current passes in one direction through a junction of two dissimilar metals, cooling is produced in the junction; if the current is reversed, the junction heats.

Conventional cooling techniques require apparatus such as compressors, motors, and cooling coils. Electronic refrigeration could greatly reduce the size and weight of cooling mechanisms. For example, a present-day 10-cubic-foot refrigerator converted to electronic operation would yield 11.5 to 12 cubic feet of usable internal space.

The bottle cooler-warmer demonstrated is less than half a cubic foot in size, including its stand and controls. The device consists of a number of junctions of semiconductor materials mounted geometrically around an anodized aluminum container. This assembly in turn is surrounded by vertical aluminum fins for air cooling. Thermostatically controlled, the device has an automatic timer mechanism that can be set up to 12 hours in advance. Thus, the appliance can be set on a cycle that will (1) cool and keep the bottle's contents at 40

A new class of thermoelectric materials is prepared on a laboratory scale in this special furnace at the Research Laboratories.

In operation at the "hot cell" of the Westinghouse materials engineering departments, samples of material and all adjustments on the "torque magnetometer" must be handled by mechanical "hands" or manipulators. Here, the sample that is being tested is mounted on the support positioned in the gap of the electromagnet.



degrees F; (2) automatically switch to warm to 100 degrees F in 15–20 minutes; (3) sound a buzzer when the cycle is completed; and (4) automatically revert to cooling after one hour.

A second version, designed for use in an automobile by plugging into the cigarette lighter outlet, also was demonstrated. Less automatic, its temperature is controlled by pushing buttons marked "cool" and "warm."

The hostess cart appears as an enclosed four-wheeled serving cart. It operates either plugged into a regular household outlet or on its own batteries. (Using household current automatically recharges the batteries.) The central portion of the enclosed cart is, in effect, a 2-cubic foot capacity refrigerator. The top section is a warming oven with a capacity of 1.3 cubic feet and maintaining a temperature of 150 degrees F.

These products were not necessarily planned for marketing, but were intended to show that the breakthrough in semiconductor materials research was important in the new product field. It demonstrates that completely new lines of products can be designed using electronic refrigeration. ■

PORCELAIN-TO-ALUMINUM SEAL

Ceramic materials engineers have devised a method for sealing aluminum to high-tension electrical porcelain. No intermediate materials or costly vacuum or atmosphere heat treatments are required. A mechanically reliable, vacuum-tight seal results of bringing high-purity aluminum and porcelain or other alumina-silica ceramics into contact under carefully controlled temperature and temperature-change conditions.

Although still a laboratory development, the new seals can be used in transformers, circuit breakers, and capacitors where the substitution of aluminum for steel or other structural materials is desirable.

The new technique eliminates the disadvantages of other sealing methods; failure by leakage of mechanical seals (threads or shrink fits) caused by differences in thermal expansion, and leakage of organic sealing and gasketing materials that deteriorate under the ambient conditions of apparatus use. In addition, other methods of making a chemically bonded seal between porcelain and aluminum require numerous costly intermediate steps.

In the new Westinghouse method, the materials required are a relatively pure aluminum and glazed or unglazed porcelain. The seal is effected by bringing the porcelain, at a high temperature, in contact with molten aluminum.

The temperatures and holding time at temperature are critical and depend on the composition of the porcelain. The rates of heating and cooling are also important in preventing damage to the porcelain by thermal shock, and in achieving a desirable grain structure in the aluminum.

Photomicrographs show a chemical bond between the two constituents. The thickness of this bond is dependent on the composition of the porcelain, the temperature, and the time at temperature.

Mechanical tests have shown that the bond material is stronger than either the aluminum or the porcelain. In fact, when a seal is destructively tested either in tension or shear, failure occurs most often in the porcelain, often in the aluminum, seldom at the joint. ■

THE HELISPHERE . . . A NEW RADAR ANTENNA

Fifty yards of drapery material, purchased in a Pittsburgh department store, have been converted by scientists at the Westinghouse Research Laboratories into a modern radar antenna. The antenna can be made in very large sizes so as

Employing a new principle of refrigeration, the device (top) cools or heats a baby's bottle and has a built-in clock timer that makes the entire operation automatic. The bottle is kept cool until shortly before the pre-selected feeding time, when automatically it is heated. When the milk reaches desired temperature, an alarm rings.

The hostess cart (center) has separate compartments which refrigerate and heat. The warming oven, maintained at 150 degrees F, is at the top and has a capacity of 1.3 cubic feet. At the bottom is a two-cubic-foot refrigerator.

The test pilot steps out of the cockpit after completing the first flight of T2J Navy trainer equipped with new model Westinghouse J34 jet engine. The turbojet is now undergoing an accelerated test program, which is designed to duplicate all phases of operation in training service. The program calls for more than 1000 flight hours on each of two J34-WE-46 engines.

to concentrate low-frequency radar waves into the intense, narrow, moving beam required for powerful, long-range, anti-missile radars of the future.

But to the electronics engineer, the radar antenna—known as a Helisphere—has an especially important advantage. It scans a complete circle without any motion of the antenna structure. In contrast, conventional radar antennas must rotate continually.

A nonrotating radar antenna has several advantages over conventional types. It permits faster scan and track rates and eliminates the driving power normally required; antenna construction is simplified and the problem of rotating bearings—especially acute in large, ground-based radar systems—is eliminated. The Helisphere secures these advantages by substituting motion of a small feed horn inside the antenna for the customary rotation of the antenna structure.

Essentially, the Helisphere antenna is a sphere, either inflated like a balloon or of rigid construction like a plastic globe. On the surface of the sphere, or imbedded in it, are narrow metal conducting strips. These strips are wound around the sphere in a multiple helix, like the stripes on a barber pole. This peculiar helical layout on the sphere gives the Helisphere its name (see back cover).

Operation of the Helisphere depends upon the fact that radar waves can be polarized. These polarized radar waves are beamed against the inside surface of the sphere, in a plane parallel to the thin conducting strips on the sphere. When so oriented, the surface acts as a focusing reflector for the radar waves projecting them toward the other side of the sphere.

Because of the nature of the helix, the strips on the opposite surface of the sphere lie at right angles to the reflected radar waves, and the waves pass through this surface and into space as a narrow radar beam.

Radar energy is fed into the antenna through a vertical, hollow tube, or wave guide. The top of the wave guide is bent at right angles and aimed horizontally at the inside surface of the antenna. Simply rotating this wave guide inside the antenna rotates the radar beam.

The "department store" version of the Helisphere antenna consists of a balloon-like cloth structure, six feet in diameter. The all-important conducting metal strips, winding spirally around the surface of the antenna, are simply the decorative metallic threads woven into the fabric when it was loomed as a drapery material. The cloth is placed around a rubber bladder and the Helisphere is inflated to shape by pumping it full of air. Only low pressures are required—approximately one-tenth psi.

Another inflated cloth structure, called a radome, completely covers the balloon-shaped Helisphere. A large plastic bag acts as a low-pressure airlock, through which the scientists enter and leave the space between the Helisphere and its radome. The radome protects the antenna from weather and keeps it stationary in the wind. Because a sphere is inherently the most stable of inflated shapes, the Helisphere is especially rigid and sturdy.

Experiments have shown that the Helisphere antenna operates effectively over a considerable range of beam elevation angles. The transmitted beam shows a width of only one degree. Spurious radiation from the sides and back of the antenna is no higher than that produced by conventional types.

Scientists see no technical reason why the Helisphere will not scale up to large sizes and eventually emerge as a highly useful and desirable type of radar antenna structure. A full-scale Helisphere would be about 100 feet in diameter. ■

PERSONALITY PROFILES

J. K. DILLARD, co-author of the article on large turbine generator units, is a South Carolinian, from the "coon hunting and moonshine country," as he puts it. An EE graduate from Georgia Tech, Dillard went on to earn his MS degree from MIT; following his graduation, he remained at MIT for three years as a member of the staff of the Department of Electrical Engineering. Dillard joined Westinghouse in 1950 as an electric utility engineer. His first assignment was in the Advanced Development section, dealing with system studies of surge protection, transient phenomena, circuit analysis, economic dispatch, and similar problems. In 1955 he was made a supervisory engineer, responsible for analog and digital computer studies of power system problems. In 1956 he became manager of Electric Utility Engineering, his present position.

Dillard is active in the AIEE; he is a member of one committee and chairman of two others. He is also a lecturer in the graduate school of the University of Pittsburgh. Dillard has made two trips to Europe for Westinghouse, one this year, where among other things he presented, at the World's Fair, the paper on which the article in this issue is based.

C. J. BALDWIN, Dillard's co-author, is a native of San Antonio, Texas. A graduate of the University of Texas, where he earned a BS in EE in 1951, and an MS in 1952, Baldwin joined Westinghouse shortly thereafter. His initial assignment was in the Advanced Development Section headed by Dillard. Here he worked on analog computer solutions for such problems as rectifier regulation and arc back, and surge protection of stations and equipment. In 1954, he became a sponsor engineer, covering Kentucky, southern Ohio, and Indiana. In 1956, Baldwin was awarded the B. G. Lamme scholarship and spent a year at MIT, where he earned the professional degree, EE, in 1957. He then returned to the Advanced Development Section where he is charged with finding new digital computer applications to power system problems. Baldwin, like Dillard, has served as a lecturer at the University of Pittsburgh, teaching transients in linear systems.

A gas turbine engineer and an electric utility engineer make an ideal team to describe the application of gas turbines on electric utility systems. R. E. STRONG, the turbine engineer, came on the Graduate Student Course in 1950 with a BSME from Cornell University. He joined the industrial gas turbine department of the Steam Division early in 1951, and has been there since. Strong has served primarily as a thermodynamic design and development engineer. One of his principal jobs has been to evaluate combined steam and gas-turbine cycles for electric power generation. Other assignments have included design coordination engineering on the development of 3000- and 12 000-hp gas turbine frames, and application of digital computers to gas turbine design problems.

W. H. FERGUSON, the electric utility engineer, attended Carnegie Institute of Technology on a George Westinghouse Scholarship. After a three-year interruption for a tour of duty with the Army Signal Corps in the South Sea Islands, he graduated in 1948 with a BSEE. He then combined his GI rights with a half interest in a Westinghouse Fellowship in Power Systems Engineering to obtain an MSEE from the Illinois Institute of Technology. He came to Westinghouse on the Graduate Student Course in 1950, and then to Electric Utility Engineering. Ferguson is presently a Sponsor Engineer for the Boston, Connecticut Valley, and New York State districts.

Ferguson's principal hobby is gardening. His home is on what he describes as "6 acres of worn out farmland," which he is restoring to productivity as he landscapes the house. He has planted some 400 trees in the last six years, and has a large vegetable garden where he experiments with a variety of crops and cultural methods. He has even equipped one room of his house with oversize windows and a concrete slab floor to serve as a small greenhouse for winter gardening.

When A. C. LORDI'S article, "Cement Plant Power," appeared in these pages last year, it was mentioned that Tony also applies electrical equipment to coal mines. His article this month about rounds out his activities at mining petroleum and chemical section of the industrial engineering department.

Outside the company, Lordi is secretary of the AIEE Mining Industry Committee and also a member of the Cement Industry Subcommittee. Since joining Westinghouse in 1954, he has submitted nine patent disclosures—all of course dealing with the cement and coal industries. This year he obtained an MSEE degree from the University of Pittsburgh. His thesis investigated the slow speed inching of synchronous motors—a method used to accurately position large ball mills in cement plants.

On the home front, Lordi has just finished a retaining wall for his driveway—you guessed it—using air-entraining portland cement wall stone. No coal projects are in sight to date.

R. L. TREMAINE has a good excuse for his absence from these pages since 1952—much of the intervening time was spent overseas. In 1954, Tremaine left his job of sponsor engineer in the electric utility engineering section to go to Germany as a resident engineering representative of Westinghouse to the Siemens companies. He traveled extensively throughout Germany, and to a lesser extent throughout Western Europe. His job involved obtaining engineering information that might be of value to Westinghouse—on everything from turbines to transistors.

Tremaine and his family lived in Erlangen, which is near Nuremberg in Southern Germany. During his stay in Germany, from 1954 until early 1958, the Tremaine family lived with German people and all of their associations were with Germans. As a matter of fact, his daughter did not learn to speak English until they returned to the United States.

Upon his return, Tremaine was made manager of the power control systems engineering section, where he works with automatic dispatching equipment, economic dispatch computers, industrial kilowatthour demand control equipment, tie line load control equipment, and data processing equipment.

Tremaine came to Westinghouse in 1940 after graduating from the University of Maine.

M. J. BROWN, who joins Tremaine to describe automatic dispatching, is a graduate of Purdue in 1928 with a BSEE. He obtained a professional EE degree from the same university in 1933. Brown joined Westinghouse in 1929 to work on the development of electronic devices, and later entered the switchgear engineering department where he concentrated on power line carrier applications. In 1940, he went into the design of switchgear for automatic control of hydroelectric generating stations.

Brown was sent to South America in 1955 to help start up the Paulo Afonso hydroelectric project. He helped coordinate the initial operation of the hydroelectric generators and transmission lines, making final tests before energizing the lines.

Shortly after his return from Brazil, Brown was placed in charge of development work on the new automatic dispatching system, and is now an Advisory Engineer on automatic dispatching equipment and other power control systems equipment. The system described in this issue was developed under his supervision.

Brown has two primary interests outside his work—travel and photography—which he manages to combine most successfully.

The *Helisphere*—a new kind of radar antenna developed by Westinghouse research scientists—produces a rotating radar beam without rotation of the antenna structure. A functional scale model (above) illustrates with a light beam the working principle of the antenna. Radar waves from a rotating source are sprayed against the inside surface of the stationary balloon-shaped antenna; the wave is reflected through the opposite side of the sphere as an intense, narrow beam. The scale model was actually used for laboratory testing with very short radar waves. A six-foot inflated model (below) of the new antenna is shown ready to emerge through the roof of the Research Laboratories for tests of its radiation pattern (see story on page 191).